AD NUMBER
AD144320
LIMITATION CHANGES
TO: **Approved for public release; distribution is unlimited.**
FROM: **Distribution authorized to U.S. Gov't. agencies and their contractors; Administrative/Operational Use; DEC 1957. Other requests shall be referred to Air Force Arnold Engineering Development Command, Tullahoma, TN 37389.**
AUTHORITY
aedc, ltr dtd 16 Jul 1993

AEDC-TR-57-20
(Brown U. TR WT-23)
ASTIA DOCUMENT NO.:
AD-144320

EXPERIMENTAL AND THEORETICAL STUDY OF MEAN BOUNDARY CONDITIONS AT PERFORATED AND LONGITUDINALLY SLOTTED WIND TUNNEL WALLS

By

C. F. Chen and J. W. Mears
Brown University
Division of Engineering

December 1957

ARNOLD ENGINEERING
DEVELOPMENT CENTER

AIR RESEARCH AND DEVELOPMENT COMMAND

US AF

AEDC-TR-57-20
(Brown U. TR WT-23)
ASTIA DOCUMENT NO.:
AD-144320

EXPERIMENTAL AND THEORETICAL STUDY OF MEAN BOUNDARY CONDITIONS AT PERFORATED AND LONGITUDINALLY SLOTTED WIND TUNNEL WALLS

By
C. F. Chen and J. W. Mears
Brown University
Division of Engineering

December 1957

This investigation was performed under the sponsorship of the United States Air Force and monitored by Arnold Engineering and Development Center under Contract AF 40(600)-677.

AF - AEDC
Tullahoma Tennessee

CONTENTS

	Page
ABSTRACT	4
NOMENCLATURE	5
INTRODUCTION	6
THEORETICAL CONSIDERATIONS FOR LONGITUDINALLY SLOTTED WALL	7
Statement of Problem and Method of Solution	7
Solution to the Problem of Uniform Flow Impinging Upon a Distribution of Slats along z-Axis	8
The Mean Boundary Condition	10
EXPERIMENTAL ARRANGEMENT	12
Wind Tunnel	12
Test Section	13
Instrumentation	14
EXPERIMENTAL PROCEDURE	14
RESULTS	16
Longitudinally Slotted Wall	16
Perforated Wall	18
REFERENCES	22

ILLUSTRATIONS

Figure		
1.	Cross-Sectional View of Slotted Wall	23
2.	Distribution of Doublet-Rods along y-Axis	23
3.	Layout of Brown University 22" x 32" Low-Speed Wind Tunnel	24
4.	Velocity Distribution in Wind Tunnel	25
5.	Slotted Wall Test Section Configurations	26
6.	Perforated Wall Test Section Configurations	27
7.	Arrangement of Perforations	28
8.	Typical Test Arrangement	29
9.	Profile of Joukowsky Airfoil	30
10.	Yawmeter and Probes	31
11.	Yawmeter Direction - Finding Tip	32
12.	Flow Direction and Pressure Difference along Test Section, Test 1	33

Figure		Page
13.	Flow Direction and Pressure Difference along Test Section, Test 2	34
14.	Flow Direction and Pressure Difference along Test Section, Test 3	35
15.	Correlation Between Streamline Curvature and Perturbation Velocity in x-Direction, Test 1	36
16.	Correlation Between Streamline Curvature and Perturbation Velocity in x-Direction, Test 2	37
17.	Correlation Between Streamline Curvature and Perturbation Velocity in x-Direction, Test 3	38
18.	Flow Direction and Pressure Difference along Test Section, Test 4	39
19.	Flow Direction and Pressure Difference along Test Section, Test 5	40
20.	Flow Direction and Pressure Difference along Test Section, Test 6	41
21.	Relation Between Pressure Coefficient and Perturbation Velocity in y-Direction, Tests 4 and 5 . .	42

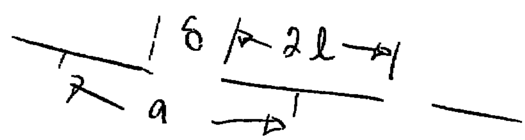
ABSTRACT

A mean boundary condition has been derived for the flow of an incompressible inviscid fluid along a longitudinally slotted wall taking into consideration the finite thickness of the slats. The flow was investigated near a wall along its longitudinal axis, and the results showed that the mean boundary condition was satisfied in the middle portion of this region.

The mean boundary condition for a perforated wall, derived by Maeder and Wood (Ref. 1), was investigated. The results showed that the mean boundary condition was not satisfied at either end of the test section. In the middle portion, the mean boundary condition would be satisfied if it were modified by an additive constant.

NOMENCLATURE

a	Center to center distance between two adjacent slats
b	Half thickness of slat
C	Constant, see equation (16)
K	Constant, see equation (8)
ℓ	Half width of slat
P	Static pressure
q	Dynamic pressure = $1/2\ \rho U^2$
U	Free stream velocity
u', v', w'	Perturbation velocities in x, y, z directions respectively
W	Complex potential
w	Complex potential
x, y, z	Rectangular Co-ordinates
Δ	Represents change in quantity it prefixes
θ	Angle of flow
μ	Doublet strength
ρ	Density
Φ	Potential
Φ'	Perturbation potential
Ψ	Stream function
$\zeta = z + iy$	Complex co-ordinates in the cross flow plane



$\delta = (a - 2\ell)$

$2\ell = a - \delta$

SUBSCRIPTS

atm	Atmospheric

INTRODUCTION

It is known that in order to attain speeds in the transonic range in the test section of a wind tunnel, some or all of the walls of the test section have to be partly open, either perforated or slotted. Choking is alleviated by these partly open walls, thus enabling a smooth transition from subsonic to supersonic flow. However, the boundary conditions to be satisfied by the air stream in the test section become complicated and a two-dimensional problem, for instance an airfoil which spans the width of the tunnel, becomes three dimensional. The exact boundary conditions for an inviscid flow in such a test section are: the normal component of velocity must vanish at the walled portion, and the pressure must be continuous at the open portion. In mathematical representation, these conditions are $\frac{\partial \phi'}{\partial n} = 0$ at the walled portion and $\phi' = 0$ at the open portion, where ϕ' is the perturbation potential and n is in the normal direction to the boundary. See Maeder and Wood [1] [1]. To solve the flow problem subjected to these conditions involves laborious numerical calculations.

It has been shown by various investigations [2], [3], [4], [5] that it is in general sufficient to replace the inhomogeneous boundary by a homogeneous mean boundary which, as seen by the model, closely approximates the inhomogeneous boundary. Maeder and Wood [1] solved the mean boundary condition for slotted walls of zero thickness with slots set at an arbitrary angle with respect to the air stream. Walls with longitudinal slots and with perforations are two special cases of the general problem they con-

[1] Numbers in brackets refer to references.

sidered. In this report, the problem of longitudinally slotted walls is solved taking into consideration the finite thickness of the slats. A mean boundary condition similar to that derived by Maeder and Wood [1] has been obtained. This condition is then compared with the results obtained in several experiments. For the perforated wall the mean boundary condition is taken from the work of Maeder and Wood [1] and is compared with the experimental results.

THEORETICAL CONSIDERATIONS FOR THE LONGITUDINALLY SLOTTED WALL

STATEMENT OF PROBLEM AND METHOD OF SOLUTION

In an incompressible inviscid flow the equation that has to be satisfied by the perturbation potential ϕ' is

$$\nabla^2\phi' = \frac{\partial^2\phi'}{\partial x^2} + \frac{\partial^2\phi'}{\partial y^2} + \frac{\partial^2\phi'}{\partial z^2} = 0 \tag{1}$$

(See Fig. 1 for the orientation of axes x, y, z). The boundary conditions are

$$\begin{aligned} v' &= \frac{\partial \phi'}{\partial y} = 0 && \text{at walled portion} \\ u' &= 0 \rightarrow \phi' = 0 && \text{in slots} \end{aligned} \tag{2}$$

It is assumed that at some distance $-\Delta y$ from the boundary (the order of magnitude of Δy will be evaluated in the course of analysis) a mean condition exists. Then the flow there may be considered as a uniform flow with perturbation velocities in the x and y-direction. In the region $-\Delta y < y < 0$

$$\frac{\partial^2\phi'}{\partial x^2} << \frac{\partial^2\phi'}{\partial y^2} + \frac{\partial^2\phi'}{\partial z^2}$$

therefore $\frac{\partial^2\phi'}{\partial x^2}$ can be neglected. In this region the problem is reduced to a uniform flow v' impinging upon a distribution of discrete slats along the z-axis. The problem can then be solved by replacing the slats with doublet-rods, and matching this flow with the flow due to a model in the tunnel. The mean boundary condition is then obtained.

SOLUTION TO THE PROBLEM OF UNIFORM FLOW IMPINGING UPON DISTRIBUTION OF SLATS ALONG z-AXIS

The complex potential due to a distribution of two-dimensional doublets of equal strength placed an equal distance, a , apart along the y-axis is given by [6] .

$$w = -\frac{\mu}{2a} \coth \frac{\pi\zeta}{a} \tag{3}$$

where μ is the strength, $\zeta = z + iy$, the complex variable.

In the case of doublet-rods placed along the y-axis extending from $(na-\ell)$ to $(na+\ell)$ where $n = -\infty, \cdots -2, -1, 0, 1, 2, \cdots \infty$ (Fig. 2) with constant strength μ , the potential due to an elementary length dy located at $i(na+y)$ is

$$dw = -\frac{\mu}{2a}\, dy \coth \frac{\pi}{a}(\zeta - iy) \tag{4}$$

Upon integration,

$$w = -\frac{i\mu}{2\pi} \log \frac{\sinh\frac{\pi}{a}(\zeta - i\ell)}{\sinh\frac{\pi}{a}(\zeta + i\ell)} \tag{5}$$

The potential of doublet-rods distributed along the z-axis can be obtained by replacing ζ in (5) by $-i\zeta$. Thus

$\zeta = z + iy$

$$W = -\frac{i\mu}{2\pi} \log \frac{\sin\frac{\pi}{a}(\zeta+l)}{\sin\frac{\pi}{a}(\zeta-l)}$$

The total complex potential of a uniform flow V in the positive y-direction superimposed on the distribution of doublet-rods along the z-axis is

$$W = iV\zeta - i\frac{\mu}{2\pi} \log \frac{\overset{-\mu x}{\sin\frac{\pi}{a}(\zeta+l)}}{\sin\frac{\pi}{a}(\zeta-l)} = \phi + i\psi \tag{6}$$

One of the boundary conditions in (2) states that ϕ has to vanish in the slots. Therefore for $\zeta = z + i0$, the following inequality must hold.

$$\frac{\sin\frac{\pi}{a}(z+l)}{\sin\frac{\pi}{a}(z-l)} > 0 \tag{7}$$

This doesn't [illegible]
since at $y=0$
W is imaginary $\Rightarrow \phi \equiv 0$

It can be easily shown that the above condition is satisfied for

$$(na + l) < z < (n+1)a - l$$

which is in the slots.

Now, the strength μ can be evaluated in terms of the thickness and the width of the slats, and the distance between slats by setting the stagnation points at the center of each slat, i.e. at $z = na$ and $y = \pm b$ where 2b is the thickness.

Thus:

$$\mu = aV\left\{\frac{\cos\frac{2\pi l}{a} - \cosh\frac{2\pi b}{a}}{\sin\frac{2\pi l}{a}}\right\} = aVK \tag{8}$$

$l = \frac{(a-\delta)}{2}$

where K is a constant which can be evaluated once the configuration of the slotted section is known. The total complex potential is then

$$W = -iV\zeta - i\frac{aV}{2\pi} K \log \frac{\sin\frac{\pi}{a}(\zeta + \ell)}{\sin\frac{\pi}{a}(\zeta - \ell)} = \phi + i\psi \tag{9}$$

THE MEAN BOUNDARY CONDITION

From (9)

$$\phi = Re\, W = Vy + \frac{aV}{2\pi} K \, Im \log \frac{\sin\frac{\pi}{a}(\zeta + \ell)}{\sin\frac{\pi}{a}(\zeta - \ell)} \tag{10}$$

where Re and Im denote real and imaginary parts respectively. Equation (10) can be rewritten as

$$\phi = Vy + \frac{aV}{2\pi} K\theta \tag{11}$$

where

$$\theta = \tan^{-1} \frac{-\sinh\frac{2\pi}{a}y \sin\frac{2\pi}{a}\ell}{\cos\frac{2\pi}{a}\ell\left[\cosh^2\frac{\pi}{a}y + \sinh^2\frac{\pi}{a}y\right] - \cos\frac{2\pi}{a}z}$$

By writing the hyperbolic functions in terms of exponentials at $y = -\Delta y$, and assuming $e^{\frac{2\pi\Delta y}{a}} >> 1$, θ can be expressed approximately as

$$\theta = \tan^{-1} \frac{\frac{1}{2} e^{\frac{2\pi\Delta y}{a}} \sin\frac{2\pi}{a}\ell}{\frac{1}{2}\cos\frac{2\pi}{a}\ell \; e^{\frac{2\pi\Delta y}{a}} - \cos\frac{2\pi}{a}z} \tag{12}$$

It is seen that Δy can be of the same order of magnitude as a. In equation (12) the term $\cos\frac{2\pi z}{a}$ in the denominator can be neglected compared with $\frac{1}{2}\cos\frac{2\pi\ell}{a} e^{\frac{2\pi\Delta y}{a}}$ if $\cos\frac{2\pi}{a}\ell \neq 0$ This condition will be satisfied if

$$\ell \neq \frac{2n-1}{4} a \qquad \text{where} \quad n = 1, 2, 3, \cdots$$

Since ℓ is the half width of the slats, it has to be less than 1/2 a. Therefore,

$$\cos \frac{2\pi}{a} \ell \neq 0 \qquad \text{if} \qquad \ell \neq \frac{1}{4} a \tag{13}$$

In practice, the open area is usually about 20% of the total area, which would make $\ell = 0.4a > \frac{1}{4} a$. Therefore, for practical cases, it can be safely assumed that $\cos \frac{2\pi}{a} \ell \neq 0$, and $\cos \frac{2\pi}{a} z$ can be neglected. Then (12) becomes

$$\theta \doteq \tan^{-1} \tan \frac{2\pi \ell}{a} = \frac{2\pi \ell}{a} \tag{14}$$

Substituting (14) into (11),

$$\phi \Big|_{y=-\Delta y} = -V\Delta y + VK\ell \tag{15}$$

V can be identified as v', the perturbation velocity in the y-direction, and ϕ as ϕ', the perturbation potential. Then the condition which must be satisfied by the perturbation potential ϕ' at the boundary y = 0 can be obtained by taking the first two terms of the Taylor Series expansion

$$\begin{aligned} \phi' \Big|_{y=0} &= \phi' \Big|_{y=-\Delta y} + \frac{\partial \phi'}{\partial y} \Big|_{y=-\Delta y} \cdot \Delta y \\ &= -v'\Delta y + v'K\ell + v'\Delta y \\ &= v'K\ell \end{aligned}$$

The physical significance of the above relationship will become apparent when it is differentiated with respect to x. At the boundary

$$\frac{\partial \phi'}{\partial x} - K\ell \frac{\partial v'}{\partial x} = 0$$

or

$$u' + C v'_x = 0 \tag{16}$$

where

$$C = \underbrace{-K\ell}$$

Since u' is proportional to the pressure difference across the boundary, equation (16) expresses the fact that the pressure difference is proportional to the streamline curvature. This mean boundary condition is of the same form as that found by Maeder and Wood [1] differing only by a constant.

EXPERIMENTAL ARRANGEMENT

The measurements were carried out in the test section of the Brown University 22 in. x 32 in. low-speed wind tunnel. The test section was capable of being fitted with either one or two perforated or slotted walls.

Two Joukowsky profiles, one, a half symmetrical section of 24-inch chord, and one, a full symmetrical section of 12-inch chord were constructed and used to create flow deflections. The deflections were measured by means of a yawmeter used in conjunction with a Betz type double micromanometer.

A more detailed description of the elements of the experimental arrangement follows.

WIND TUNNEL

All measurements were carried out in the Brown University subsonic wind tunnel. The tunnel, which is of the open circuit type, is driven by a

100 hp constant-speed motor and is capable of generating air speeds up to 200 feet per second in a 22 in. x 32 in. test section without diffuser (Fig. 3). The flow velocity in the test section is adjusted by varying the pitch of the compressor blades by means of a hydraulic mechanism which can be operated while the tunnel is running. By means of this apparatus, speed adjustments within 0.2 mm of water column in dynamic pressure are possible. After passing through the compressor, the air is decelerated in the diffuser and enters the settling chamber in which a set of three screens equalize turbulence fluctuations. The air then passes through the nozzle into the test section. A typical velocity distribution, as measured in the test section, is shown in Fig. 4.

TEST SECTION

The test section, 50 inches in overall length, was fitted with removable top and bottom walls (Fig. 5 and 6). For the slotted wall tests, the walls were .375 inches thick and consisted of ten slats 2.75 inches wide and 44 inches long separated by a distance of 0.5 inches. This gave an opening area which was 14.1% of the total area.

The perforated walls, which were interchangeable with the slotted walls, were made from 16 gage perforated sheet steel with perforations arranged as shown in Fig. 7 giving an open area 22.5% of the total area. They were perforated for 42 inches of their length.

In order to create known deflections in the air flow a Joukowsky airfoil was placed in the test section. Two configurations were investigated:

a) A half Joukowsky airfoil with 24-inch chord and maximum thickness of 4 inches placed on the lower solid wall.

b) A full Joukowsky airfoil with 12-inch chord and maximum thickness of 4 inches placed on the tunnel axis (Fig. 8).

The shape of the airfoil cross-section is shown in Fig. 9.

INSTRUMENTATION

The pressure measurements were carried out by means of a double Betz type water micromanometer. This allows a measuring accuracy of 0.1 mm of water over a range of 0 to 300 mm. The air speed measurement in the test section was obtained by measuring the pressure difference between the settling chamber and the atmosphere. This measurement gave the dynamic head q which was used in the subsequent calculations. In order to measure the flow direction a yawmeter based on the design of Dr. G. Daetwyler of Zurich, Switzerland and Prof. J. Ackeret of the Institute for Aerodynamics, Swiss Federal Institute of Technology was used (Fig. 10). It measured the direction of flow from horizontal within 0.1 degrees. The direction finding tip (Fig. 11) could be replaced by a pressure probe which would then be properly oriented with respect to the flow direction. The yawmeter was mounted on a rigid stand outside the test section with the probe extending through a 1 inch slot in the side wall 2 inches below the top wall. (Fig. 8).

EXPERIMENTAL PROCEDURE

The experimental procedure followed for each test section configuration was basically the same. The yawmeter was installed and a reference level established. The tunnel was adjusted to a speed corresponding to a dynamic head of 50 mm of H_2O, i.e. 93 feet per second in the test section. The flow direction was measured 2 inches below the top wall at intervals of 2 inches along the longitudinal test section dimension for 36 inches of its length. Measurements were taken at approximately the center of the wall in the case of the perforated wall and below a central slat and adjacent slot in the case of the slotted wall. It can be seen from Figs. 12, 13, and 14 that a distance of 2 inches below the wall is sufficiently far away from the wall for the measurements below slot and slat to be the same for most of the range.

Once the flow direction was established the static pressure probe was inserted and the difference between true static pressure and atmospheric pressure at each point determined.

This procedure yielded all the necessary data, from which the desired quantities were obtained in the following manner.

Perturbation velocity along tunnel axis, u':

If Bernoulli's equation is written between an opening in the wall and some point at which the perturbation effects are averaged, it becomes for an incompressible flow of density ρ

$$p + \frac{\rho}{2}\left[(U+u')^2 + v'^2\right] = p_{atm} + \frac{\rho}{2}\left[U^2 + v'^2\right]$$

where p_{atm} represents the pressure outside the wall, in this case atmospheric. If the squares of the perturbation velocities are neglected, the equation simplifies to

$$\Delta p = p - p_{atm} \doteq -\rho U u'$$

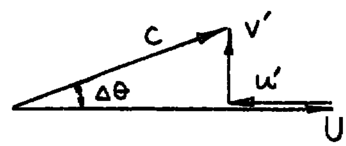
From which u' is dimensionlessly

$$\frac{u'}{U} = -\frac{\Delta p}{2q}$$

where q is known from the tunnel speed setting.

The perturbation velocity normal to the wall v':

From the velocity diagram



$v' \doteq U(\Delta\theta)$ or dimensionlessly $\frac{v'}{U} \doteq \Delta\theta$

For the case of the slotted wall, $\frac{\partial v'}{\partial x}$ was evaluated graphically, and the constant C defined in equation (16) for this arrangement of slotted section is 5.75 inches.

RESULTS

LONGITUDINALLY SLOTTED WALL

Three tests with different test section configurations were performed (Fig. 5).

Test 1). A 24-inch chord half Joukowsky airfoil placed on the bottom wall 15 inches downstream of the beginning of the test section, top wall slotted.

Test 2). The same half airfoil placed 25 inches downstream of the beginning of the test section, top wall slotted.

Test 3). Two parallel slotted walls at the top and the bottom of the test section with a 12-inch chord symmetrical Joukowsky airfoil similar to that used in 1) and 2) mounted in the center of the test section 20 inches downstream of the beginning of the test section.

The data obtained in tests 1), 2), and 3) are presented in Figs. 11, 12, and 13, respectively. It can be seen that the flow direction 2 inches below a slot and that below a slat is practically the same except in the rear portion of the test section. The same is true for the pressure readings, however, to avoid congestion of the graphs only the pressure readings 2 inches below a slot are presented. The differences in flow direction and the static pressure below a slot and those below a slat in the rear portion of the test section are attributed to the separation of the airstream flowing from outside into the test section.

The values of $\frac{u'}{U}$ and $\frac{C}{U}\frac{\partial v'}{\partial x}$ corresponding to each measuring station for the three tests are presented in Figs. 14, 15, and 16. In the calculation of $\frac{u'}{U}$, the pressure difference measured 2 inches below a slot was used. It is seen that for the tests with the top wall slotted (Fig. 14 and 15) the mean boundary condition is satisfied almost exactly in the middle portion of the test section. The discrepancy in the front portion maybe attributed to the finite length of the test section. In fact, near the beginning of the slots, the assumption that

$$\frac{\partial^2 \phi'}{\partial x^2} << \frac{\partial^2 \phi'}{\partial y^2} + \frac{\partial^2 \phi'}{\partial z^2}$$

is evidently not valid. Therefore agreement with the theoretical predictions cannot be expected. In the rear portion, the separation of in-flow would invalidate the mean boundary condition.

It was in the hope of reducing the end effects that the test with two parallel slotted walls was made. However, as can be seen in Fig. 16, the results were in poorer agreement with the theory than tests 1) and 2). Although no measurement was made of the airflow direction at the center of the test section without the airfoil, it was surmised from the measurement made with two parallel perforated walls (see section V, B) that the jet issuing from the nozzle was not horizontal. If this were the case, the experimental results would not be in accord with what was predicted with the theory set forth in section II, and the mean boundary conditions would have to be altered to satisfy this case. Due to the solid boundary at the bottom wall, the air flow is necessarily horizontal and thus symmetrical in tests 1) and 2) so that the mean boundary condition applies.

It can be concluded from these results that if the flow is symmetrical and if the stipulation on the size of the slots are met (eq. 13) this mean boundary condition approximates closely the exact flow phenomenon.

PERFORATED WALL

It has been the assumption that the pressure difference across a perforated wall in a test section is proportional to the velocity in the direction perpendicular to the wall, v' in this case. In this formulation of the mean boundary condition, i.e. $p = K v'$, the viscous nature of the fluid has been neglected. Indeed, this mean boundary condition can be derived theoretically by assuming inviscid flow and by recognizing that the perforated wall has the same characteristics as a transverse slotted wall, as shown by Maeder and Wood [1] . It has been the belief that although air is inherently viscous, the viscous effects will be predominant only in the boundary layer and the mean boundary condition would be a good first order approximation to the real flow phenomenon.

In the test results obtained, the above assumption was shown to be incorrect even to the first order, that is, the viscous effects have to be taken into account. Three tests with different test section configurations were performed (see Fig. 6):

Test 4). A 24-inch chord half Joukowsky airfoil placed on the bottom wall 25 inches downstream of the beginning of the test section, top wall perforated.

Test 5). The same airfoil arrangement as in 4) but with top perforated wall diverged 1.5 degrees.

Test 6). Two parallel perforated walls, at the top and the bottom of the test section, with a 12-inch chord symmetrical Joukowsky airfoil similar to that used in 4) and 5) mounted in the center of the test section 20 inches downstream of the beginning of the test section. The test results are shown in Figs. 18, 19, and 20. It can be seen that in all these tests, when the pressure difference across the perforated wall is zero, there is a flow outwards. This result has been shown in a previous investigation by Maeder [7] . If the case of a jet issuing into stagnant air is considered, the pressure has to be continuous across the jet boundaries, that is the pressure difference is zero. However, there is definitely a component of velocity in the direction perpendicular to the jet boundaries, since the jet width increases with distance (see for example Schlichting [8]). The flow with perforated wall boundaries is analogous to that of a free jet, therefore it cannot be expected that the y-direction perturbation velocity vanishes as the pressure difference across the boundary vanishes.

In Fig. 21 $\frac{\Delta p}{q}$ is plotted against $\frac{v'}{U}$ for test 4). It is seen that the linear relationship approximately holds in the middle portion of the curve. Considerable discrepancy exists in the first and the third quadrant of the graph. The data obtained near the beginning of the test section are plotted in the first quadrant and show an almost constant value of $\frac{v'}{U}$ with varying $\frac{\Delta p}{q}$. This may be explained by the fact that being a finite perforated wall, the initial stage of the flow is restricted by the entrance section. The flow deflection is small even though the pressure difference seems to warrant a greater one. In the third quadrant the points are data obtained near the end of the section, a constant $\frac{\Delta p}{q}$ corresponds to varying $\frac{v'}{U}$. This may again be due to the finite length of the perforated wall section.

The results obtained with the top perforated wall diverged 1.5 degrees (test 5) were plotted on the same graph (Fig. 21). It is to be noted that since the top wall is divergent, the values of $\frac{v'}{U}$ were calculated by

$$\frac{v'}{U} = \frac{\pi}{180} \left(\Delta\theta - 1.5 \right)$$

It can be seen from the graph that the results have the same characteristics as those obtained in test 4, that is, a linear relationship exists between $\frac{\Delta p}{q}$ and $\frac{v'}{U}$ for the middle portion of the curve, while at the two ends, a discrepancy exists. It is to be noted that the intercepts at $\frac{\Delta p}{q}$, and $\frac{v'}{U}$ axes are different in these two cases.

The results obtained with two parallel perforated walls (test 6) showed no linear relationship between $\frac{\Delta p}{q}$ and $\frac{v'}{U}$ at any portion of the curve. It was found upon further experimental investigation that with an empty test section, the flow direction at the center of the test section was -1.6 degrees. It was therefore concluded that with two perforated walls the airstream issuing from the convergent nozzle is deflected upwards about 1.6 degrees. Calculations were made again by reducing all the flow direction readings by

1.6 degrees. These results did not show any linear relationship between $\frac{\Delta p}{q}$ and $\frac{v'}{U}$ at all. It may be attributed to the fact that with a deflected airstream coming into the test section, the simple analysis no longer holds.

It can be concluded from these results that a linear relationship between $\frac{\Delta p}{q}$ and $\frac{v'}{U}$ does exist in a portion of the test section away from the two ends. The linear relationship should be corrected, however, by an additional constant. This additional constant cannot be evaluated without going into the exact nature of the flow.

REFERENCES

1. Maeder, Paul F., Wood, Albert D., Transonic Wind Tunnel Test Sections, ZAMP, Vol. VII, 1956, Fasc. 3.

2. Davis, Don D. Jr., Moore, Dewey, Analytical Study of Blockage- and Lift-Interference Corrections for Slotted Tunnels Obtained by The Substitution of an Equivalent Homogeneous Boundary for the Discrete Slots, NACA - RM 153E07B, June, 1953.

3. Maeder, P. F., Theoretical Investigation of Subsonic Wall Interference In Rectangular Slotted Test Sections, Brown University, Division of Engineering, Technical Report WT-11, Sept., 1953.

4. Goethert, B. H., Flow Establishment and Wall Interference in Transonic Wind Tunnels, Arnold Engineering Development Center Report AEDC-TR-54-44, June, 1954.

5. Guderley, Gottfried, Simplifications of the Boundary Conditions at a Wind Tunnel Wall with Longitudinal Slots, Aircraft Laboratory, Wright Air Development Center. WADC Technical Report 53-150, April, 1953.

6. Lamb, Sir Horace, Hydrodynamics, 6th Edition, Dover, New York, 1945, (p. 71).

7. Maeder, P. F., Investigation of the Boundary Condition at a Perforated Wall, Brown University, Division of Engineering, Technical Report, WT-9, May, 1953.

8. Schlichting, Hermann, Boundary Layer Theory, McGraw-Hill New York, 1955, (p. 485)

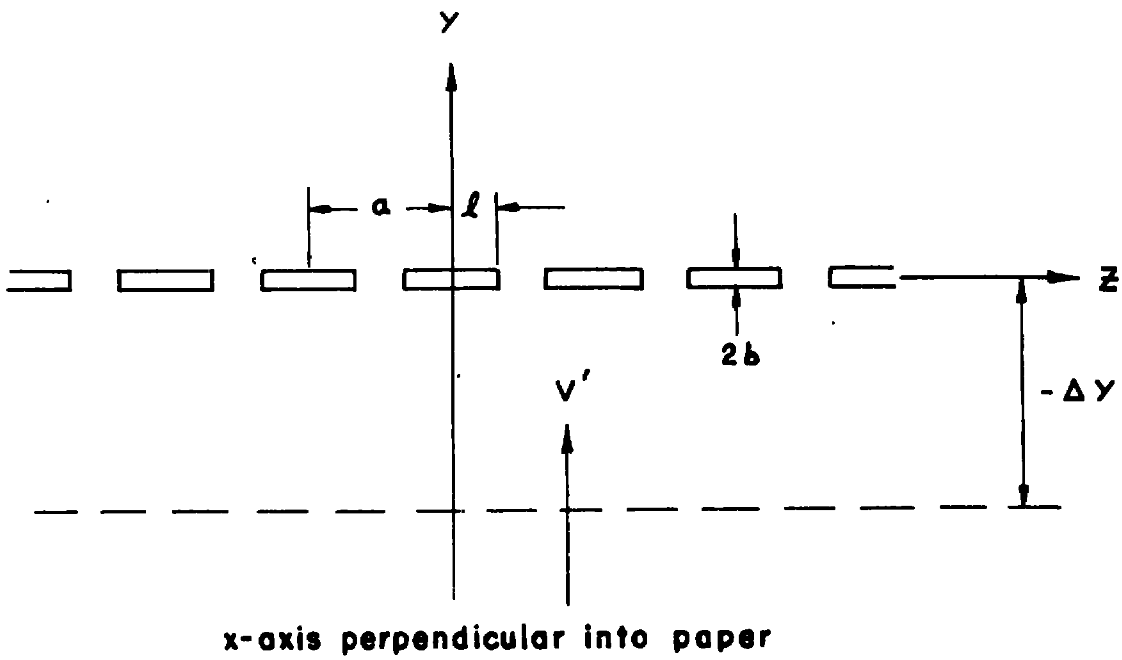


Fig. 1. Cross-Sectional View of Slotted Wall

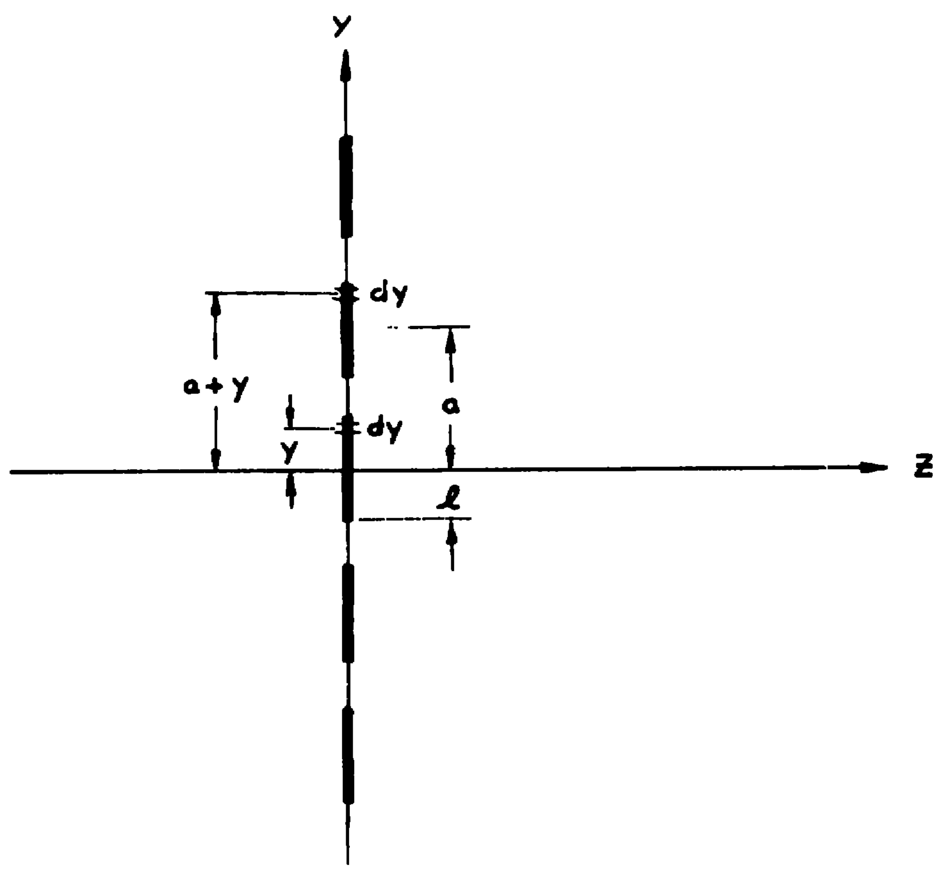
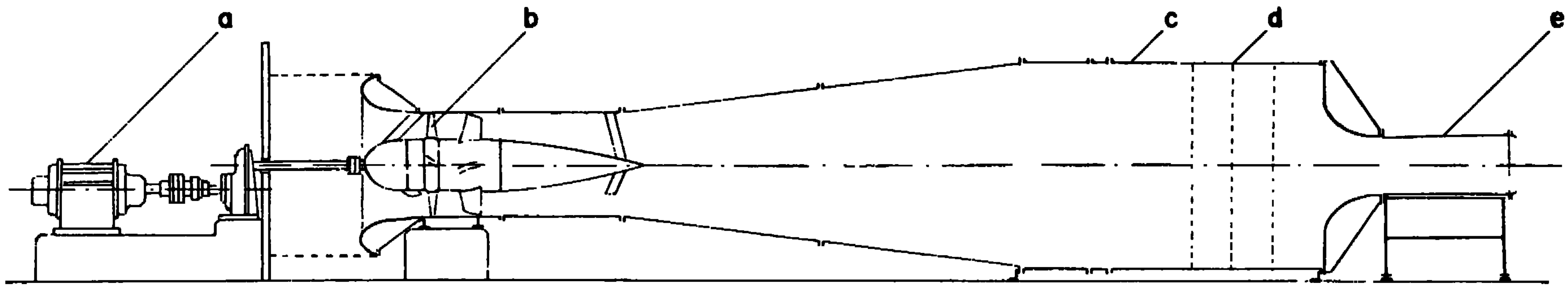


Fig. 2. Distribution of Doublet-Rods along y-Axis



a. MOTOR
b. FAN (ADJUSTABLE PITCH BLADES)
c. SETTLING CHAMBER
d. SCREENS
e. TEST SECTION

Fig. 3. Layout of Brown University 22" x 32" Low-Speed Wind Tunnel

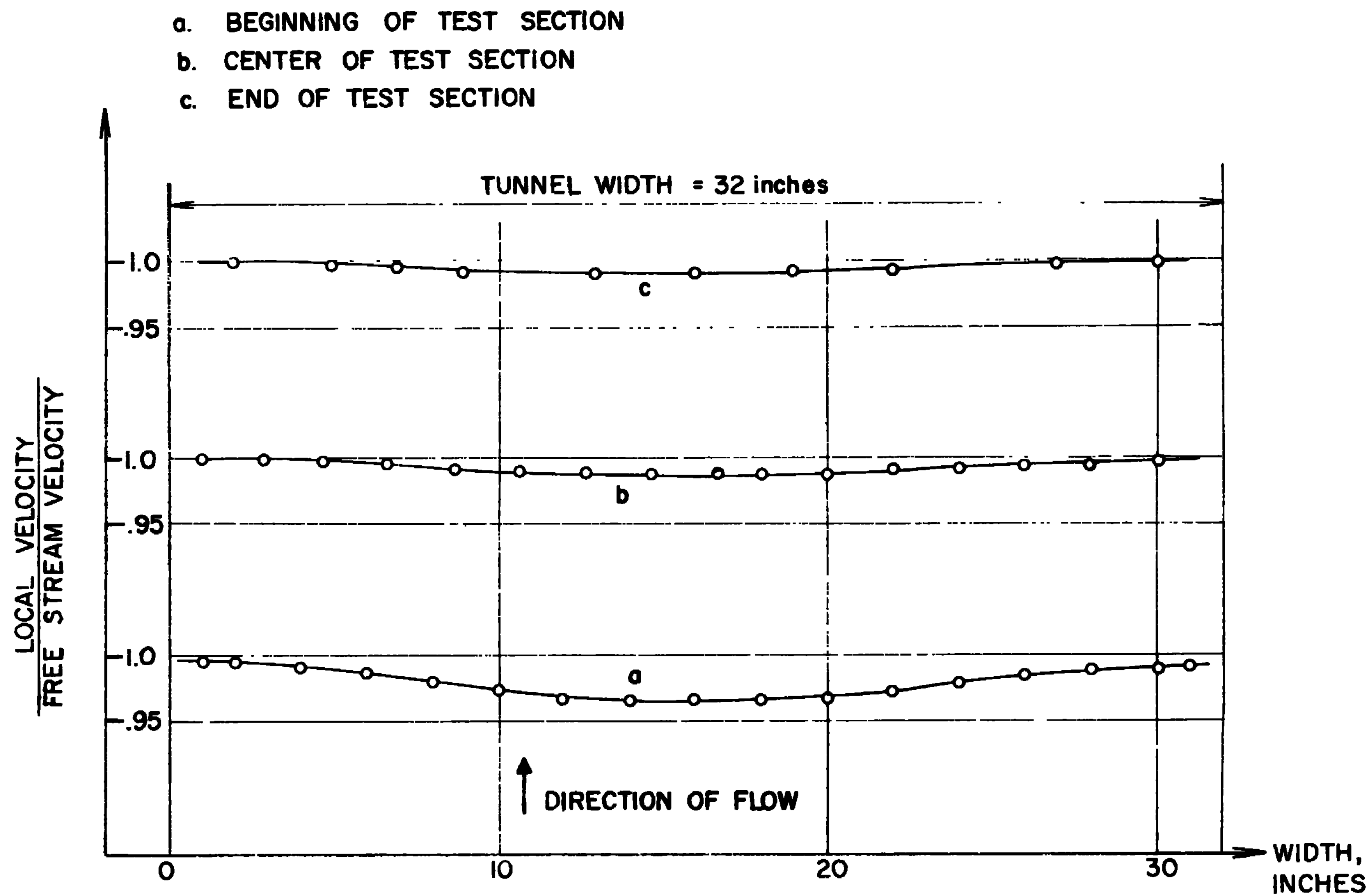


Fig. 4. Velocity Distribution in Wind Tunnel

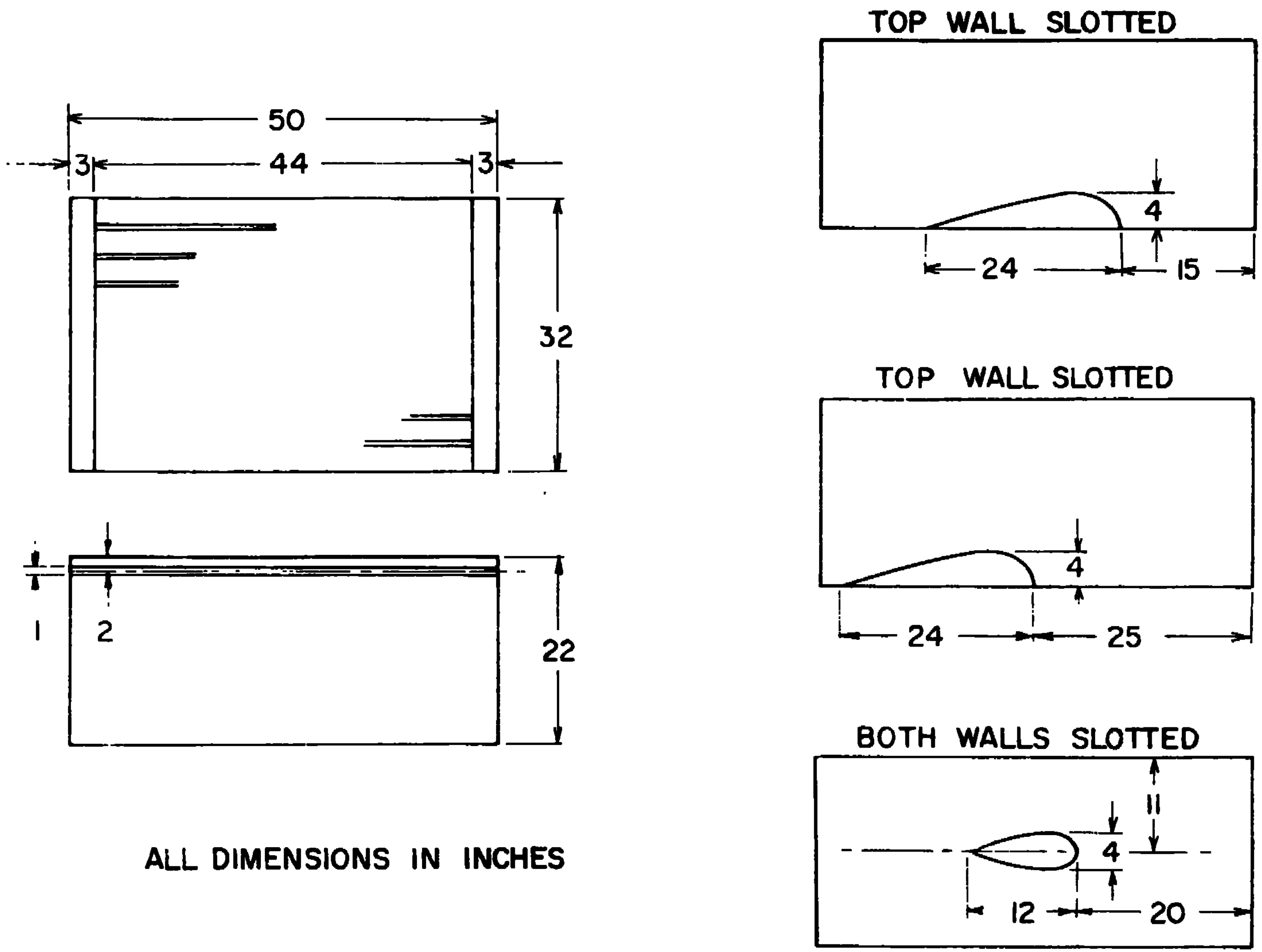


Fig. 5. Slotted Wall Test Section Configurations

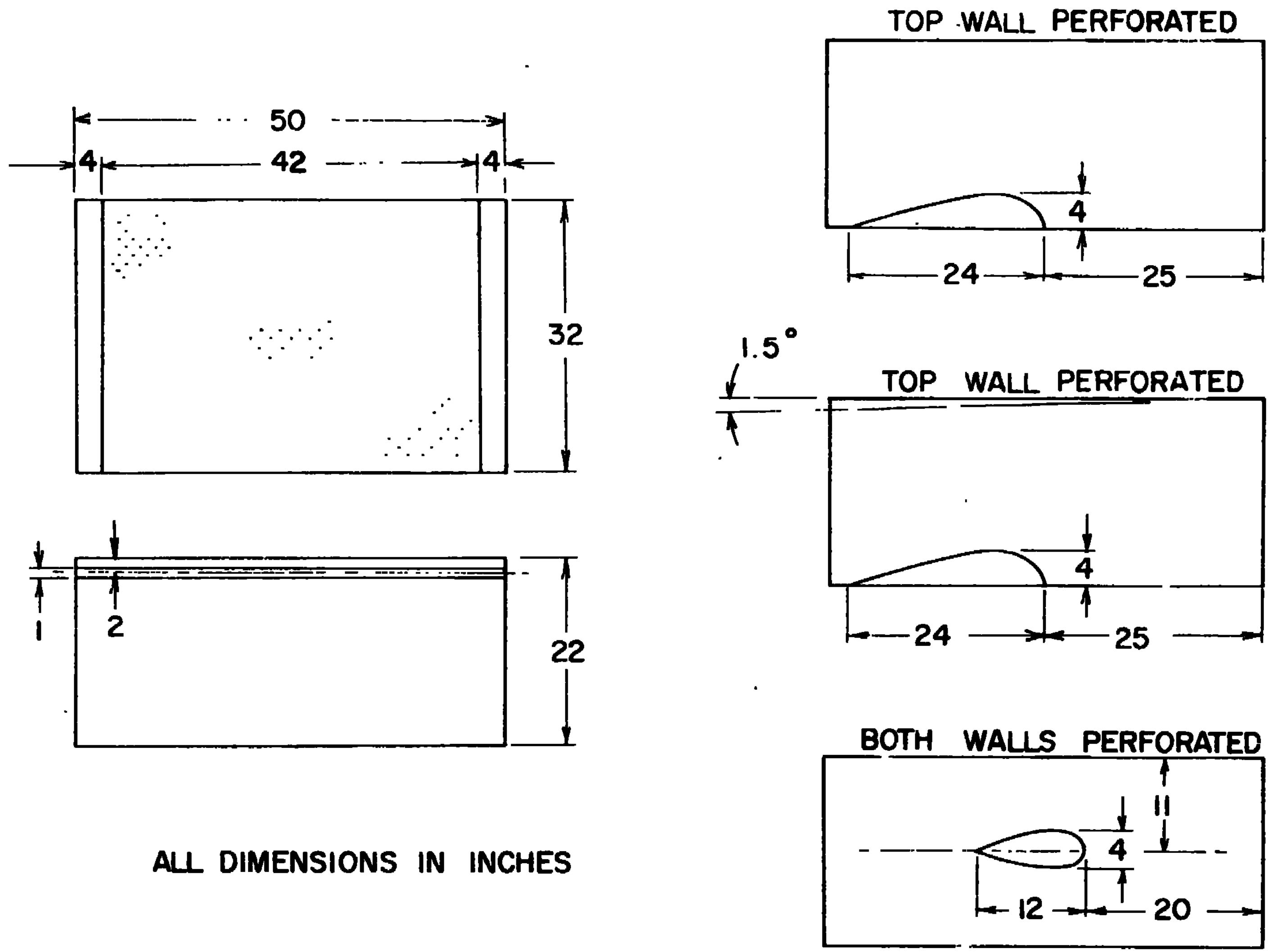
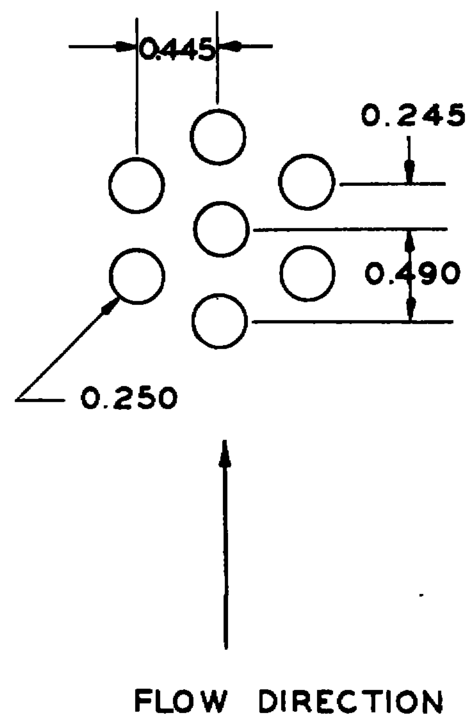


Fig. 6. Perforated Wall Test Section Configurations



ALL DIMENSIONS IN INCHES

Fig. 7. Arrangement of Perforations

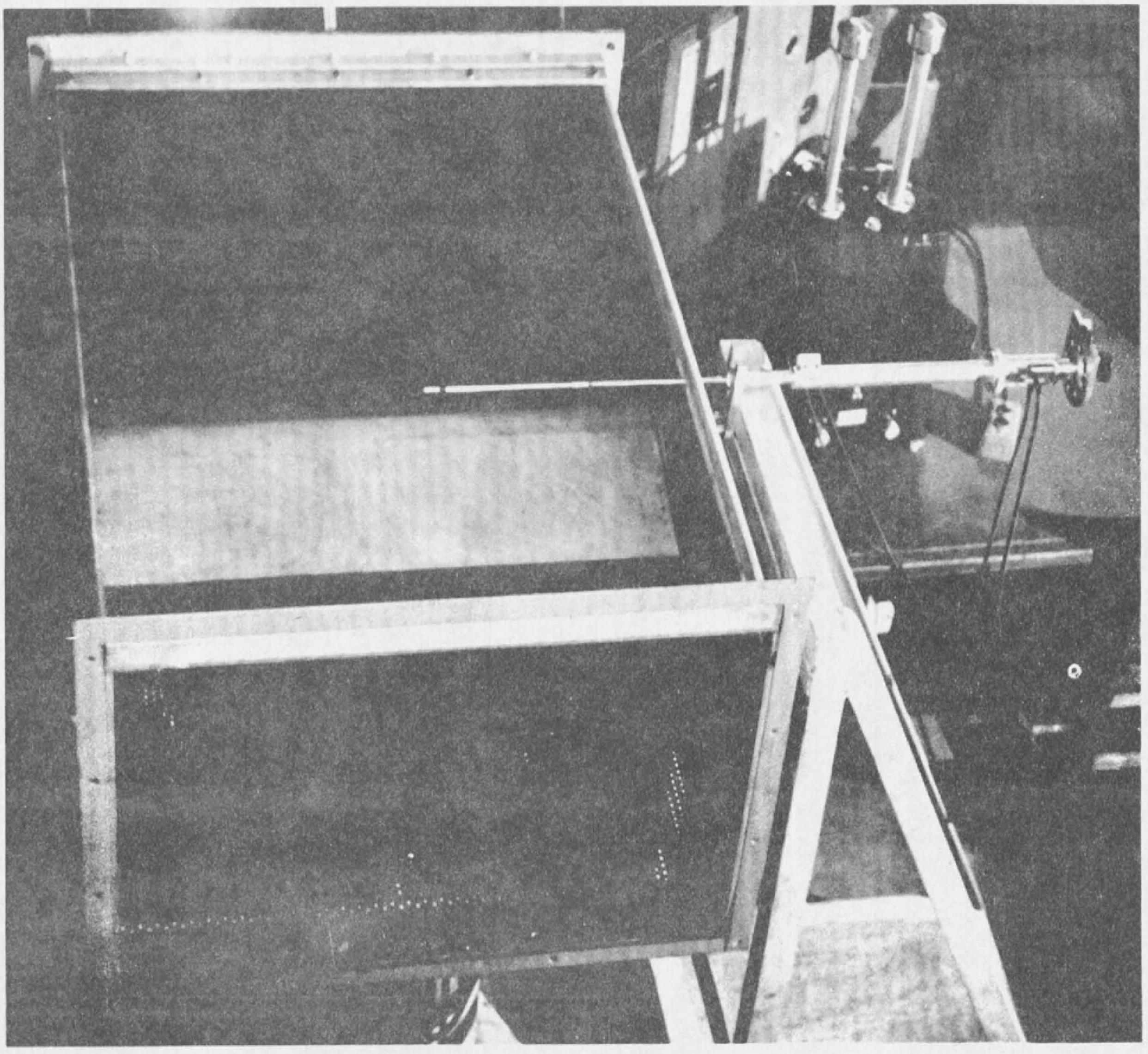


Fig. 8. Typical Test Arrangement

X	0	0.50	1.50	2.50	3.50	4.50	5.50	6.50	7.50	8.50	9.50	10.50	11.50	12.06
Y	0	1.05	1.66	1.92	2.00	1.94	1.76	1.50	1.20	0.90	0.58	0.30	0.08	0

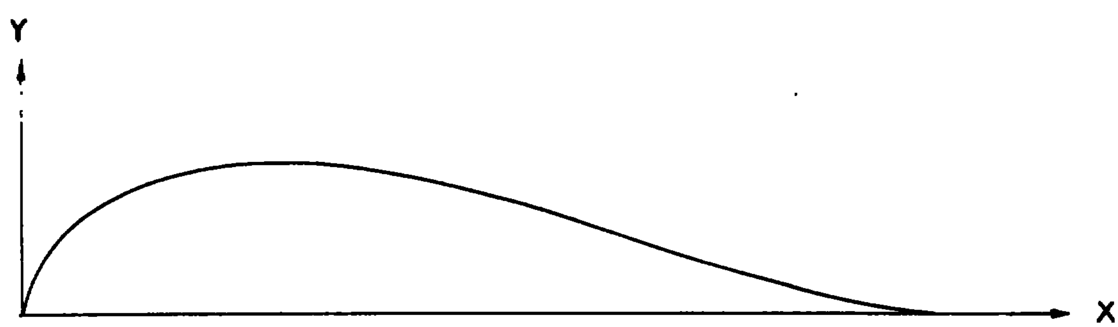
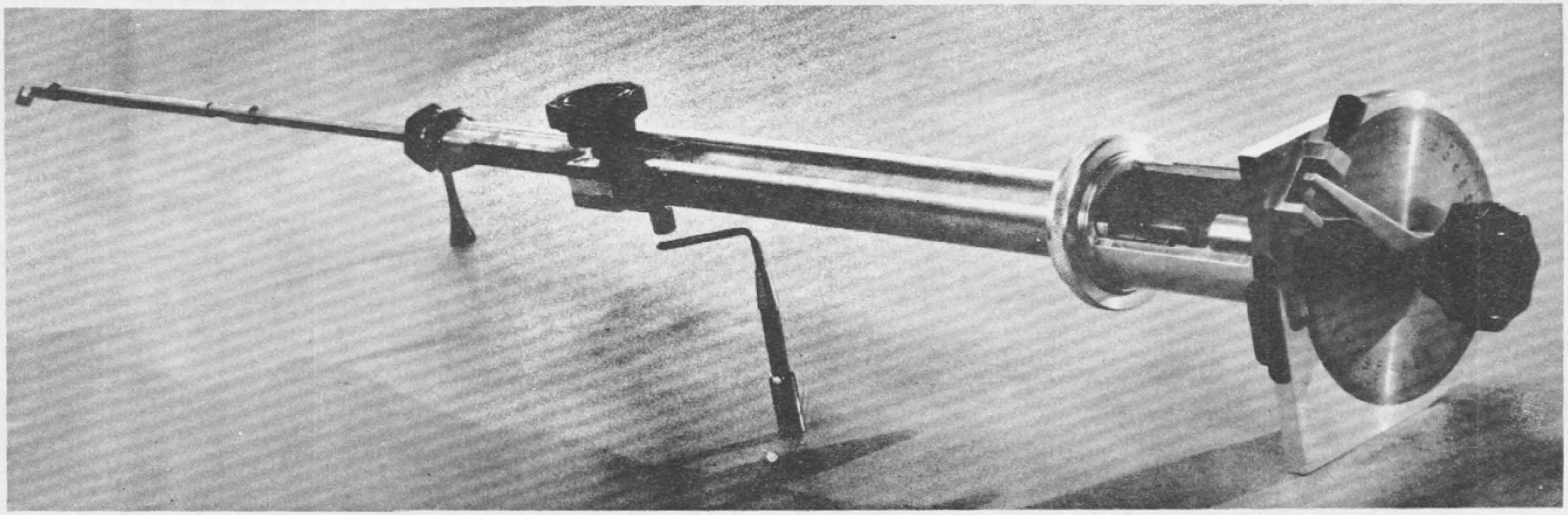


Fig. 9. Profile of Joukowsky Airfoil



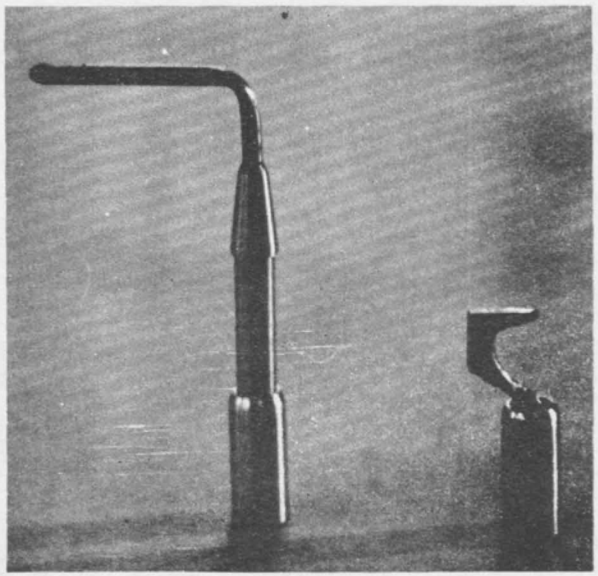
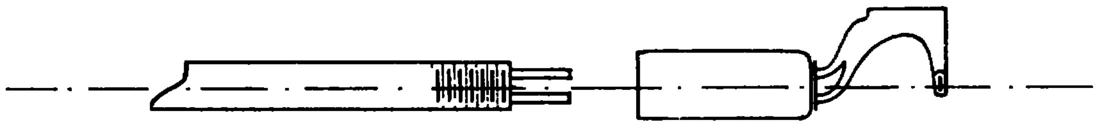
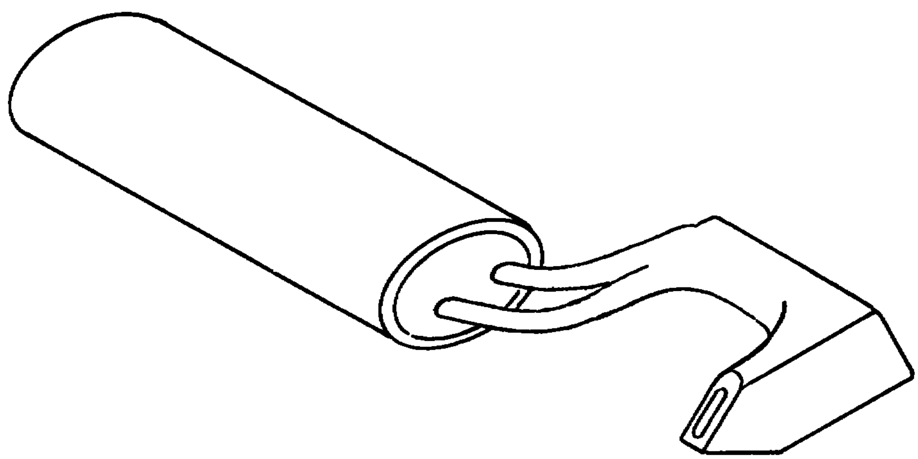


Fig. 10. Yawmeter and Probes



ACTUAL SIZE



2.5 TIMES ACTUAL SIZE

Fig. 11. Yawmeter Direction – Finding Tip

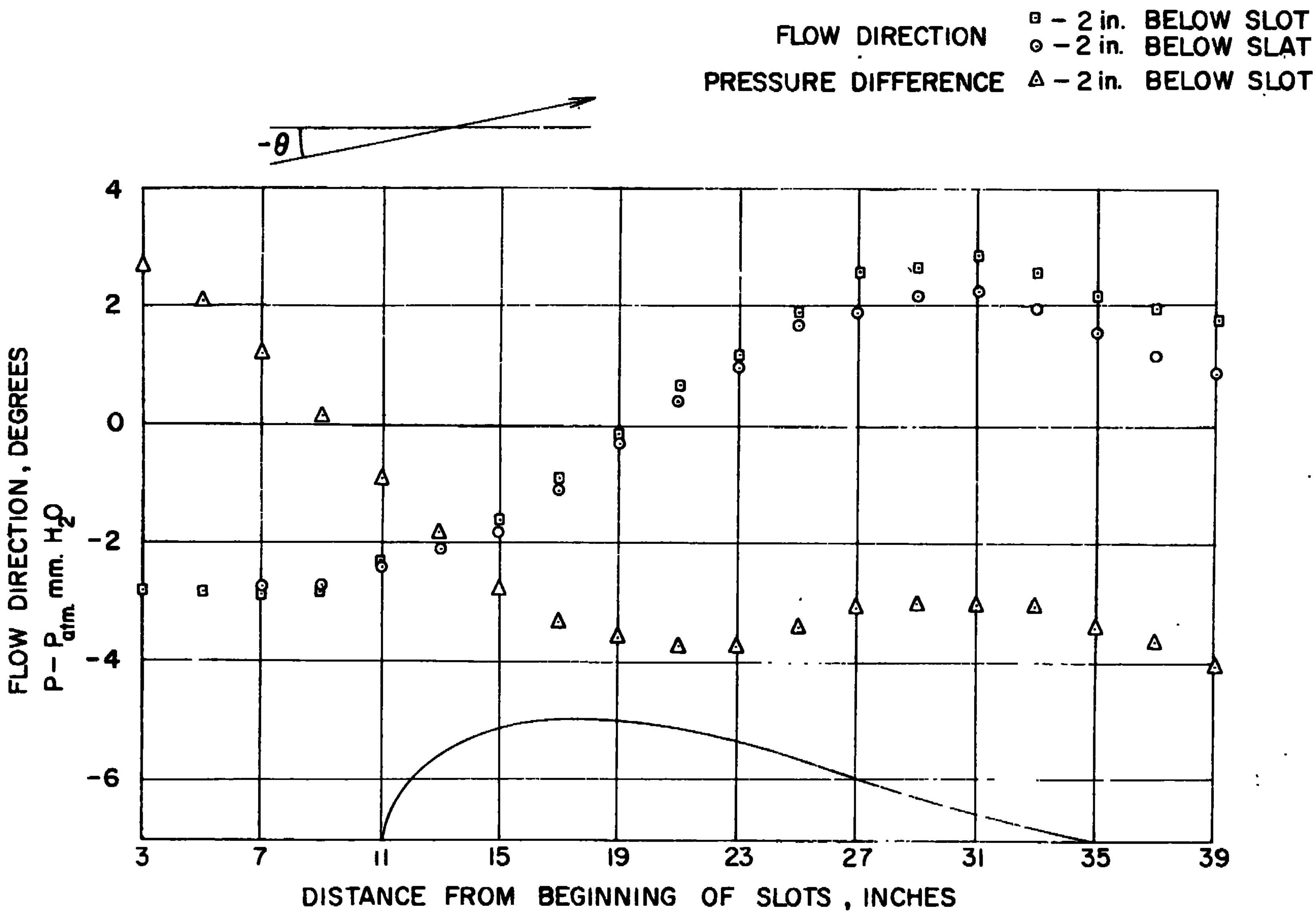


Fig. 12. Flow Direction and Pressure Difference along Test Section, Test 1

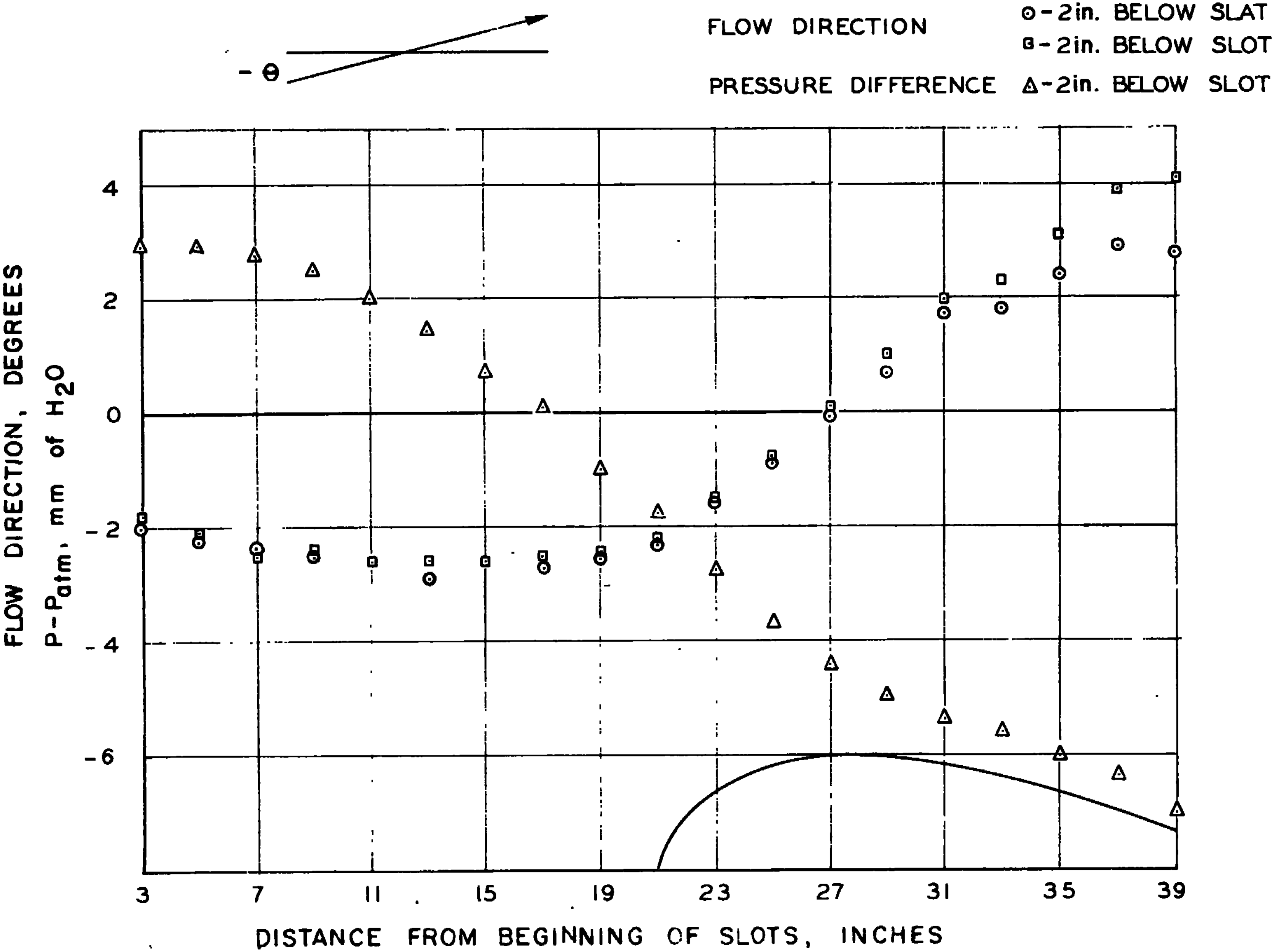


Fig. 13. Flow Direction and Pressure Difference along Test Section, Test 2

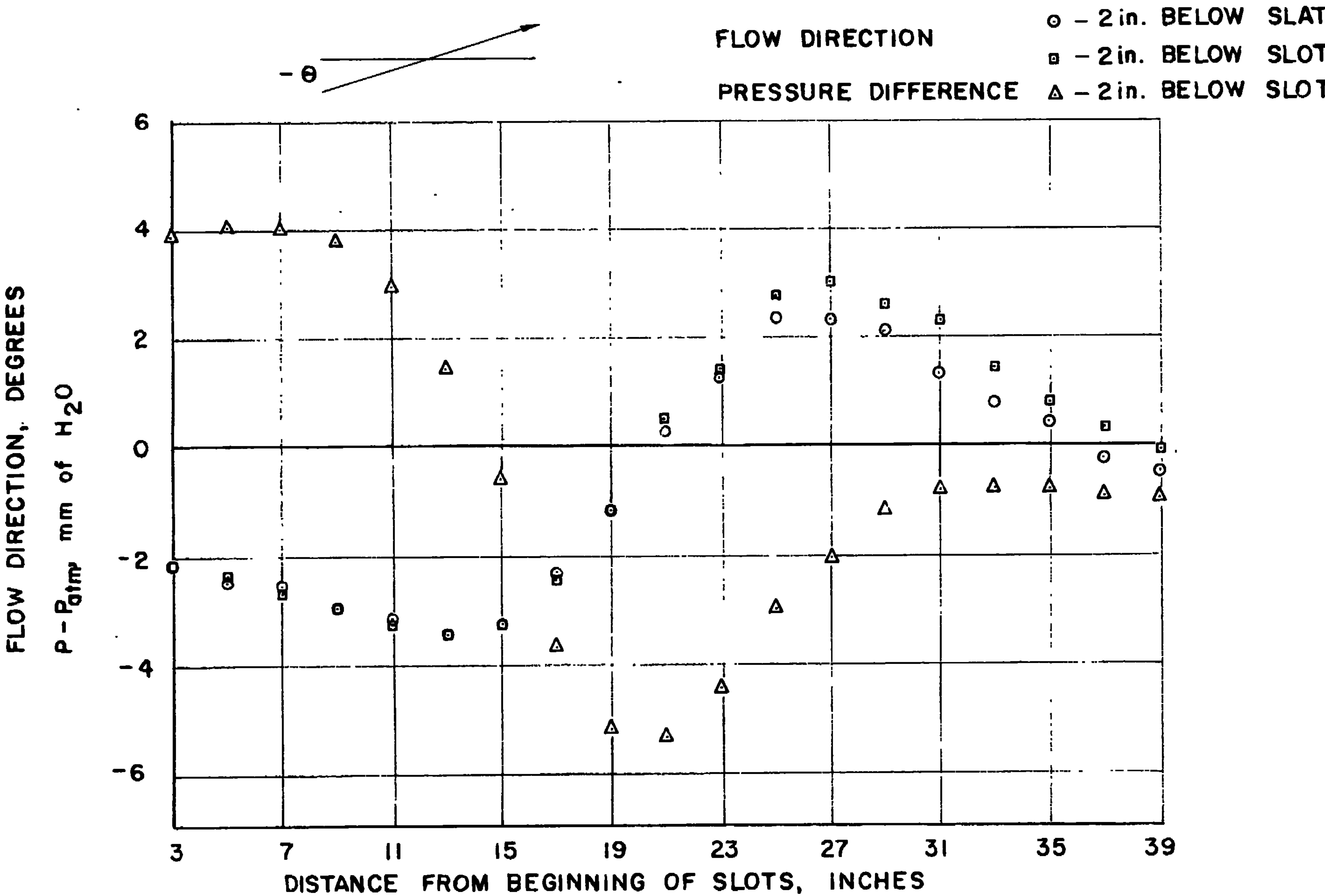


Fig. 14. Flow Direction and Pressure Difference along Test Section, Test 3

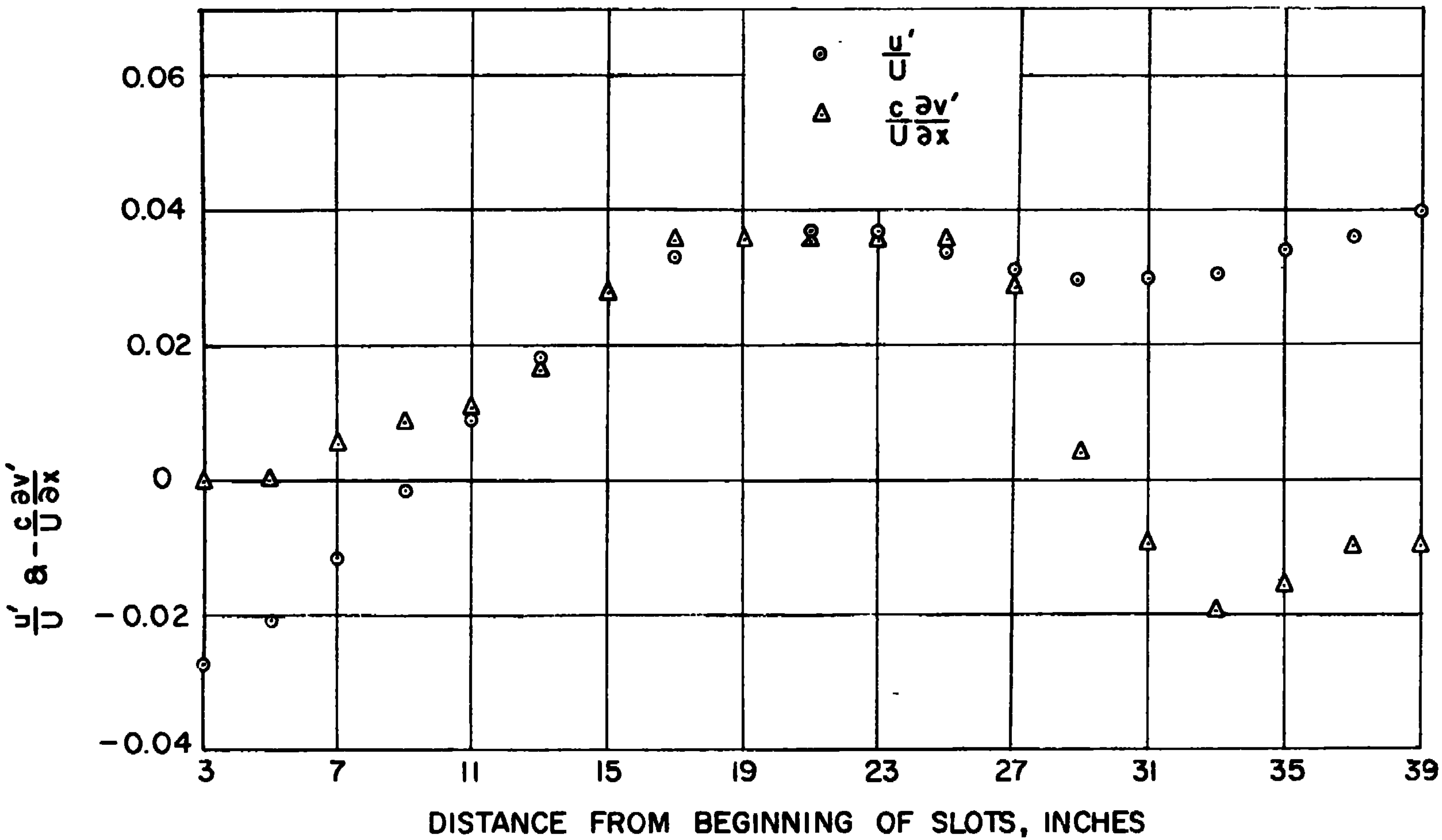


Fig. 15. Correlation Between Streamline Curvature and Perturbation Velocity in x-Direction, Test 1

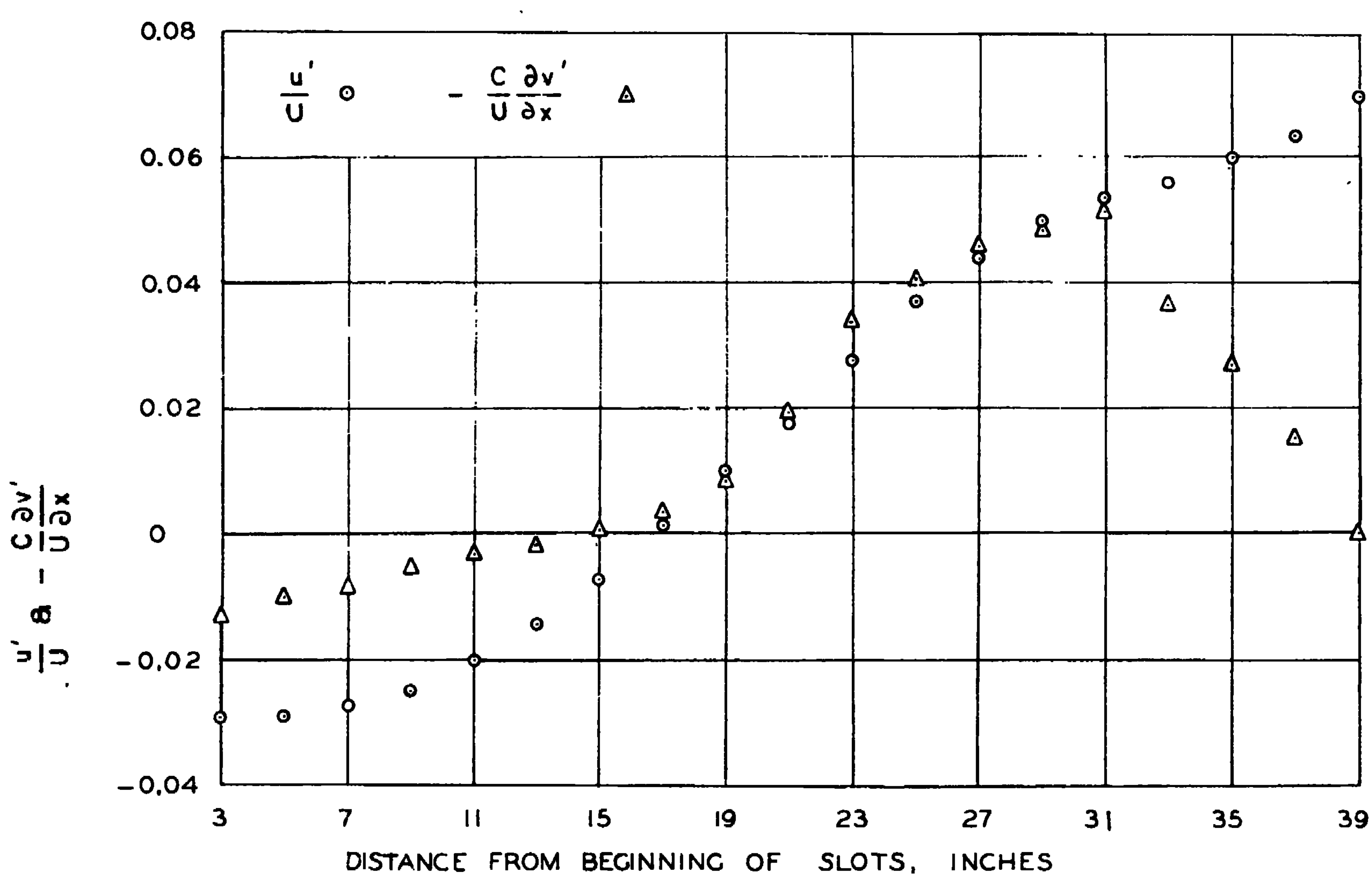


Fig. 16. Correlation Between Streamline Curvature and Perturbation Velocity in x-Direction, Test 2

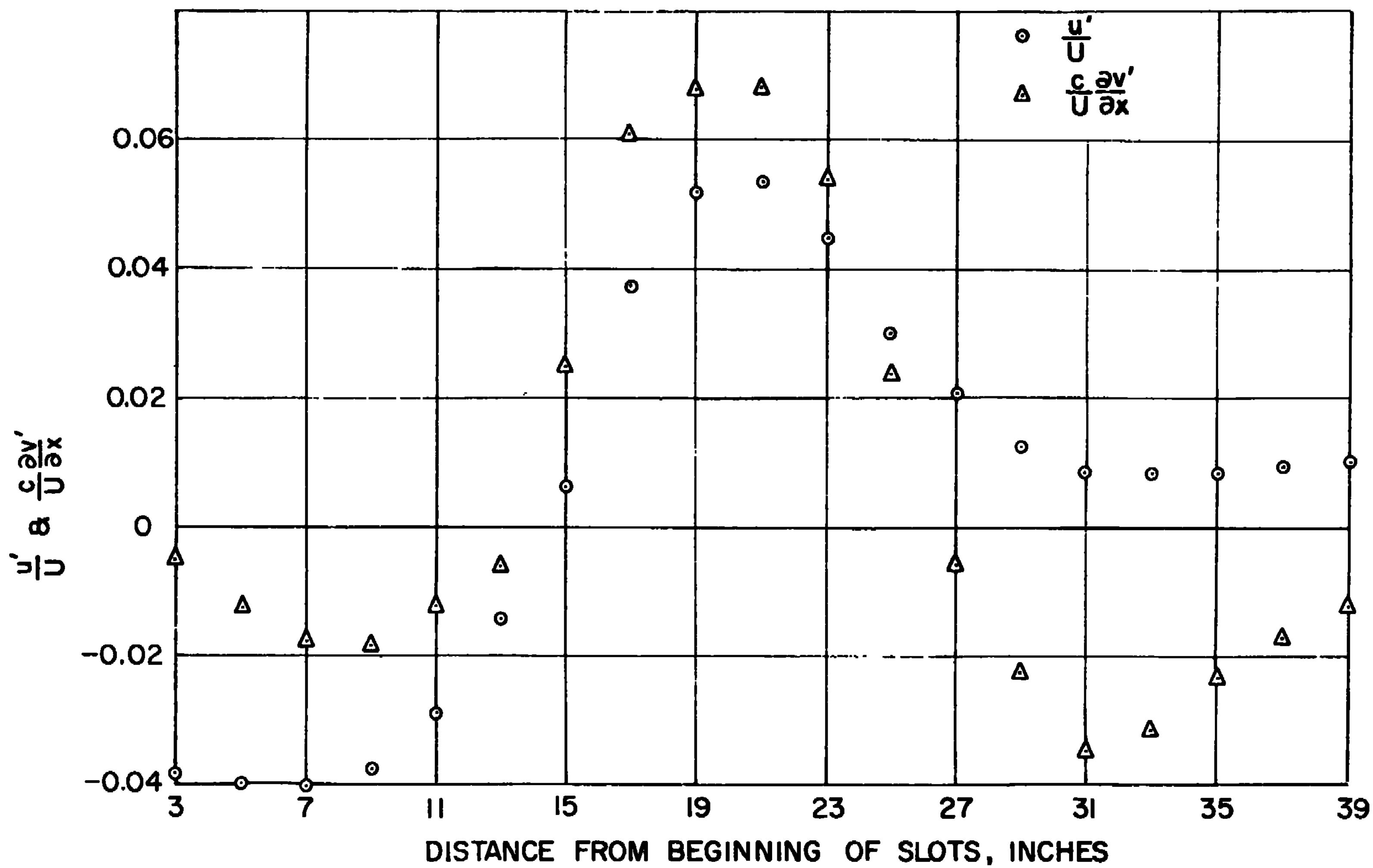


Fig. 17. Correlation Between Streamline Curvature and Perturbation Velocity in x-Direction, Test 3

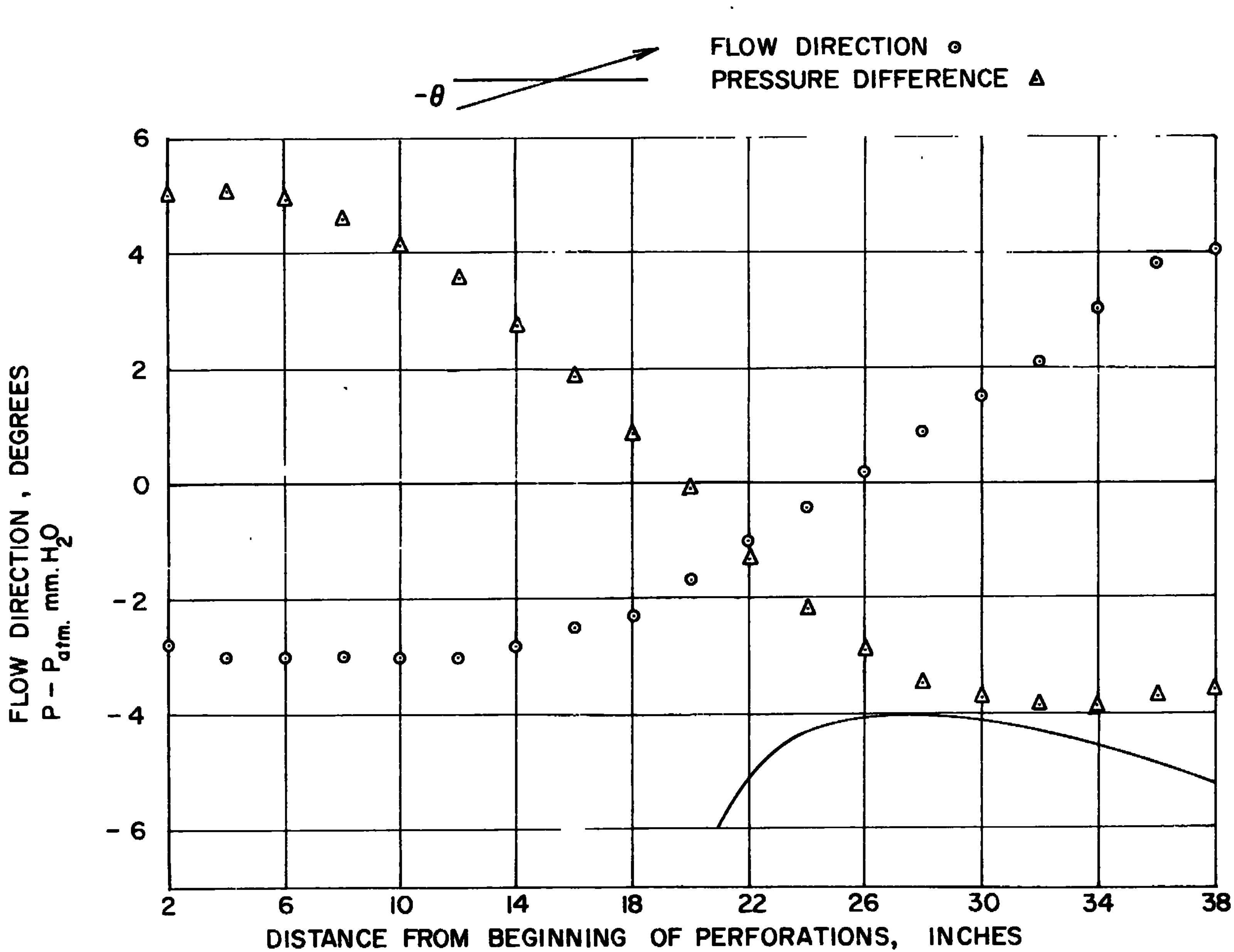


Fig. 18. Flow Direction and Pressure Difference along Test Section, Test 4

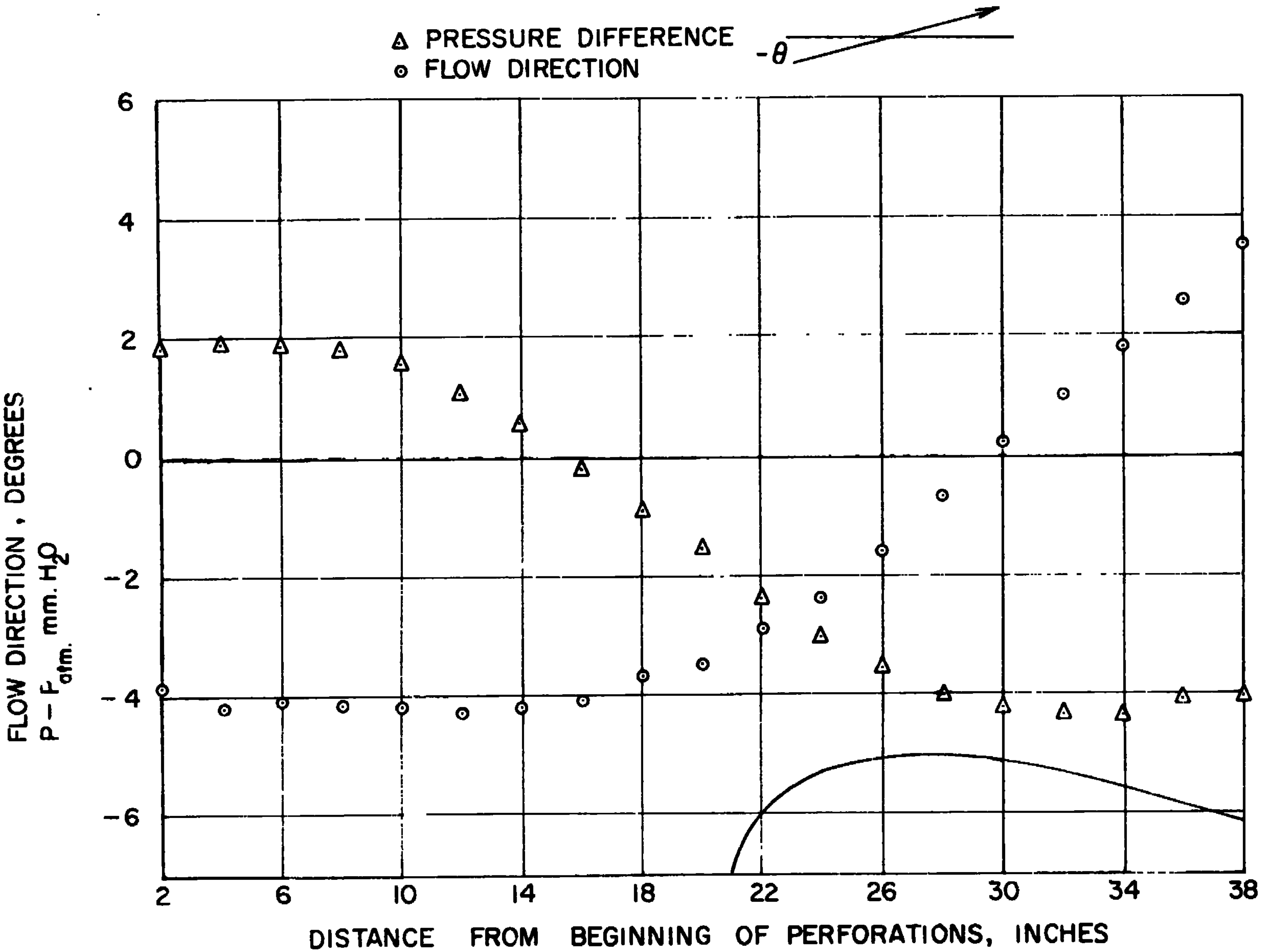


Fig. 19. Flow Direction and Pressure Difference along Test Section, Test 5

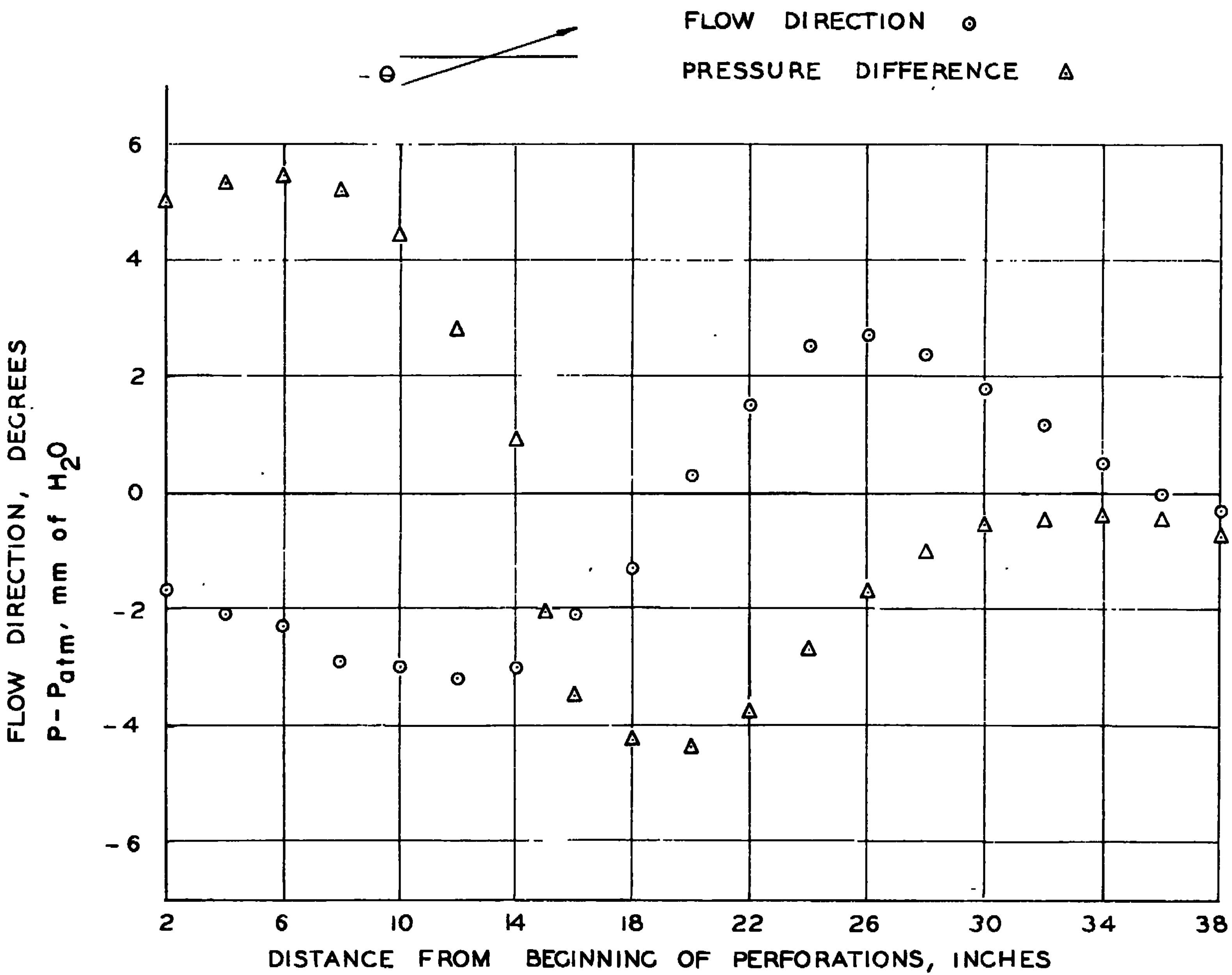


Fig. 20. Flow Direction and Pressure Difference along Test Section, Test 6

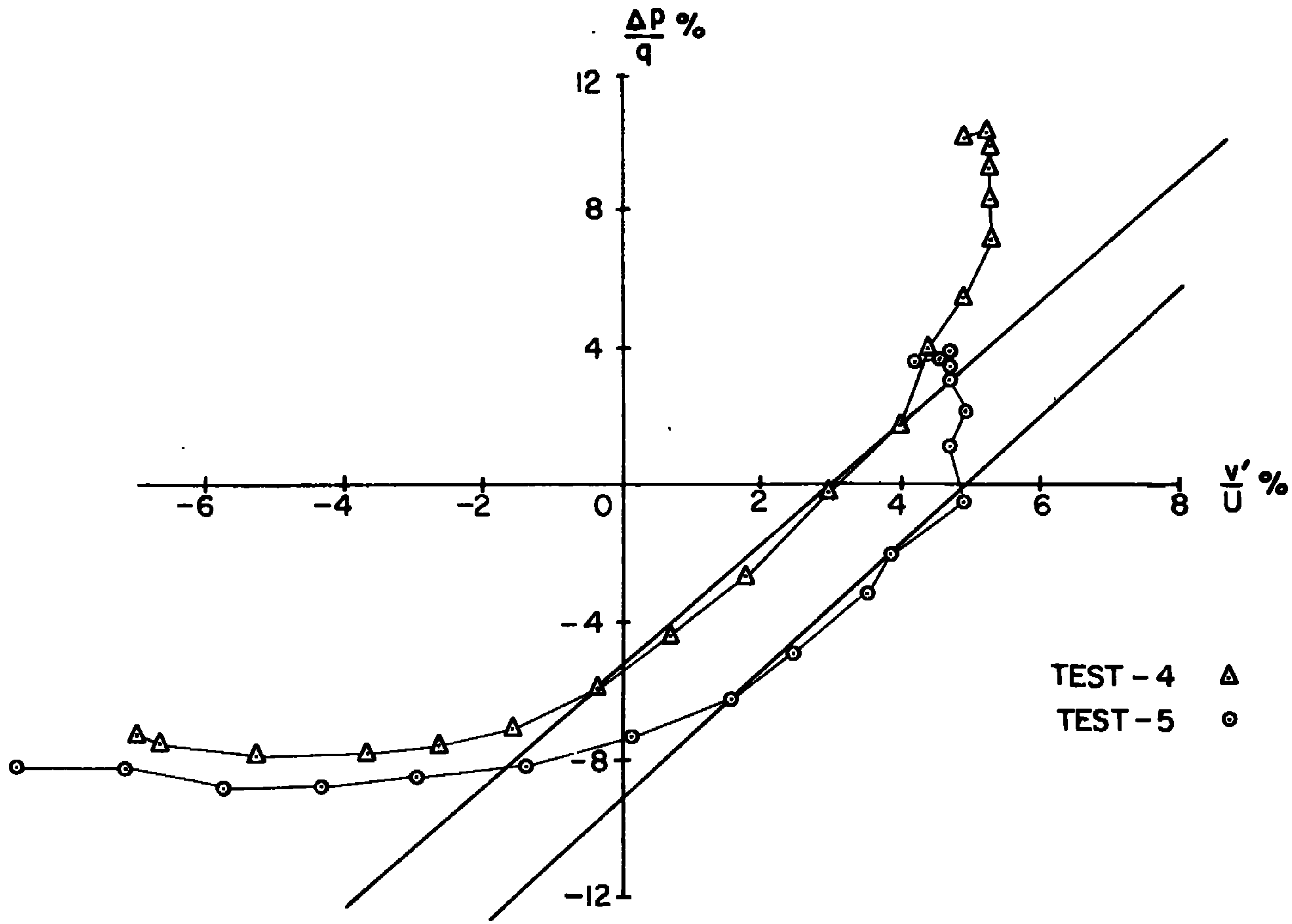


Fig. 21. Relation Between Pressure Coefficient and Perturbation Velocity in y-Direction, Tests 4 and 5.

Cut on dotted line

Cut on dotted line

UNCLASSIFIED

AEDC-TR-57-20
(Brown U. TR WT-23)
ASTIA DOCUMENT NO.:
AD-144320

Arnold Engineering Development Center, ARO, Inc., Tullahoma, Tennessee
EXPERIMENTAL AND THEORETICAL STUDY OF MEAN BOUNDARY CONDITIONS AT PERFORATED AND LONGITUDINALLY SLOTTED WIND TUNNEL WALLS by C. F. Chen and J. W. Mears, December 1957. 42 pp. (AEDC-TR-57-20) (Contract No. AF 40(600)-677) Unclassified Report

8 references

A mean boundary condition has been derived for the flow of an incompressible inviscid fluid along a longitudinally slotted wall taking into consideration the finite thickness of the slats. The flow was investigated near a wall along its longitudinal axis, and the results showed that the mean boundary condition was satisfied in the middle portion of this region.

1. Slotted test section walls--Flow
2. Perforated test section walls--Flow
3. Transonic test sections--Configurations

I. Chen, C. F.
II. Mears, J. W.

UNCLASSIFIED

UNCLASSIFIED

AEDC-TR-57-20
(Brown U. TR WT-23)
ASTIA DOCUMENT NO.:
AD-144320

Arnold Engineering Development Center, ARO, Inc., Tullahoma, Tennessee
EXPERIMENTAL AND THEORETICAL STUDY OF MEAN BOUNDARY CONDITIONS AT PERFORATED AND LONGITUDINALLY SLOTTED WIND TUNNEL WALLS by C. F. Chen and J. W. Mears, December 1957. 42 pp. (AEDC-TR-57-20) (Contract No. AF 40(600)-677) Unclassified Report

8 references

A mean boundary condition has been derived for the flow of an incompressible inviscid fluid along a longitudinally slotted wall taking into consideration the finite thickness of the slats. The flow was investigated near a wall along its longitudinal axis, and the results showed that the mean boundary condition was satisfied in the middle portion of this region.

1. Slotted test section walls--Flow
2. Perforated test section walls--Flow
3. Transonic test sections--Configurations

I. Chen, C. F.
II. Mears, J. W.

UNCLASSIFIED

UNCLASSIFIED

AEDC-TR-57-20
(Brown U. TR WT-23)
ASTIA DOCUMENT NO.:
AD-144320

Arnold Engineering Development Center, ARO, Inc., Tullahoma, Tennessee
EXPERIMENTAL AND THEORETICAL STUDY OF MEAN BOUNDARY CONDITIONS AT PERFORATED AND LONGITUDINALLY SLOTTED WIND TUNNEL WALLS by C. F. Chen and J. W. Mears, December 1957. 42 pp. (AEDC-TR-57-20) (Contract No. AF 40(600)-677) Unclassified Report

8 references

A mean boundary condition has been derived for the flow of an incompressible inviscid fluid along a longitudinally slotted wall taking into consideration the finite thickness of the slats. The flow was investigated near a wall along its longitudinal axis, and the results showed that the mean boundary condition was satisfied in the middle portion of this region.

1. Slotted test section walls--Flow
2. Perforated test section walls--Flow
3. Transonic test sections--Configurations

I. Chen, C. F.
II. Mears, J. W.

UNCLASSIFIED

UNCLASSIFIED

AEDC-TR-57-20
(Brown U. TR WT-23)
ASTIA DOCUMENT NO.:
AD-144320

Arnold Engineering Development Center, ARO, Inc., Tullahoma, Tennessee
EXPERIMENTAL AND THEORETICAL STUDY OF MEAN BOUNDARY CONDITIONS AT PERFORATED AND LONGITUDINALLY SLOTTED WIND TUNNEL WALLS by C. F. Chen and J. W. Mears, December 1957. 42 pp. (AEDC-TR-57-20) (Contract No. AF 40(600)-677) Unclassified Report

8 references

A mean boundary condition has been derived for the flow of an incompressible inviscid fluid along a longitudinally slotted wall taking into consideration the finite thickness of the slats. The flow was investigated near a wall along its longitudinal axis, and the results showed that the mean boundary condition was satisfied in the middle portion of this region.

1. Slotted test section walls--Flow
2. Perforated test section walls--Flow
3. Transonic test sections--Configurations

I. Chen, C. F.
II. Mears, J. W.

UNCLASSIFIED

AEDC-TR-57-20
(Brown U. TR WT-23)
ASTIA DOCUMENT NO.:
AD-144320

The mean boundary condition for a perforated wall, derived by Maeder and Wood (Ref. 1), was investigated. The results showed that the mean boundary condition was not satisfied at either end of the test section. In the middle portion, the mean boundary condition would be satisfied if it were modified by an additive constant.

UNCLASSIFIED

UNCLASSIFIED

AEDC-TR-57-20
(Brown U. TR WT-23)
ASTIA DOCUMENT NO.:
AD-144320

The mean boundary condition for a perforated wall, derived by Maeder and Wood (Ref. 1), was investigated. The results showed that the mean boundary condition was not satisfied at either end of the test section. In the middle portion, the mean boundary condition would be satisfied if it were modified by an additive constant.

UNCLASSIFIED

UNCLASSIFIED

UNCLASSIFIED

AEDC-TR-57-20
(Brown U. TR WT-23)
ASTIA DOCUMENT NO.:
AD-144320

The mean boundary condition for a perforated wall, derived by Maeder and Wood (Ref. 1), was investigated. The results showed that the mean boundary condition was not satisfied at either end of the test section. In the middle portion, the mean boundary condition would be satisfied if it were modified by an additive constant.

UNCLASSIFIED

UNCLASSIFIED

UNCLASSIFIED

AEDC-TR-57-20
(Brown U. TR WT-23)
ASTIA DOCUMENT NO.:
AD-144320

The mean boundary condition for a perforated wall, derived by Maeder and Wood (Ref. 1), was investigated. The results showed that the mean boundary condition was not satisfied at either end of the test section. In the middle portion, the mean boundary condition would be satisfied if it were modified by an additive constant.

UNCLASSIFIED

Cut on dotted line

UNCLASSIFIED

AEDC-TR-57-20
(Brown U. TR WT-23)
ASTIA DOCUMENT NO.:
AD-144320

Arnold Engineering Development Center, ARO, Inc., Tullahoma, Tennessee
EXPERIMENTAL AND THEORETICAL STUDY OF MEAN BOUNDARY CONDITIONS AT PERFORATED AND LONGITUDINALLY SLOTTED WIND TUNNEL WALLS by C. F. Chen and J. W. Mears, December 1957. 42 pp. (AEDC-TR-57-20) (Contract No. AF 40(600)-677) Unclassified Report

8 references

A mean boundary condition has been derived for the flow of an incompressible inviscid fluid along a longitudinally slotted wall taking into consideration the finite thickness of the slats. The flow was investigated near a wall along its longitudinal axis, and the results showed that the mean boundary condition was satisfied in the middle portion of this region.

1. Slotted test section walls--Flow
2. Perforated test section walls--Flow
3. Transonic test sections--Configurations
I. Chen, C. F.
II. Mears, J. W.

UNCLASSIFIED

UNCLASSIFIED

AEDC-TR-57-20
(Brown U. TR WT-23)
ASTIA DOCUMENT NO.:
AD-144320

Arnold Engineering Development Center, ARO, Inc., Tullahoma, Tennessee
EXPERIMENTAL AND THEORETICAL STUDY OF MEAN BOUNDARY CONDITIONS AT PERFORATED AND LONGITUDINALLY SLOTTED WIND TUNNEL WALLS by C. F. Chen and J. W. Mears, December 1957. 42 pp. (AEDC-TR-57-20) (Contract No. AF 40(600)-677) Unclassified Report

8 references

A mean boundary condition has been derived for the flow of an incompressible inviscid fluid along a longitudinally slotted wall taking into consideration the finite thickness of the slats. The flow was investigated near a wall along its longitudinal axis, and the results showed that the mean boundary condition was satisfied in the middle portion of this region.

1. Slotted test section walls--Flow
2. Perforated test section walls--Flow
3. Transonic test sections--Configurations
I. Chen, C. F.
II. Mears, J. W.

UNCLASSIFIED

Cut on dotted line

UNCLASSIFIED

AEDC-TR-57-20
(Brown U. TR WT-23)
ASTIA DOCUMENT NO.:
AD-144320

Arnold Engineering Development Center, ARO, Inc., Tullahoma, Tennessee
EXPERIMENTAL AND THEORETICAL STUDY OF MEAN BOUNDARY CONDITIONS AT PERFORATED AND LONGITUDINALLY SLOTTED WIND TUNNEL WALLS by C. F. Chen and J. W. Mears, December 1957. 42 pp. (AEDC-TR-57-20) (Contract No. AF 40(600)-677) Unclassified Report

8 references

A mean boundary condition has been derived for the flow of an incompressible inviscid fluid along a longitudinally slotted wall taking into consideration the finite thickness of the slats. The flow was investigated near a wall along its longitudinal axis, and the results showed that the mean boundary condition was satisfied in the middle portion of this region.

1. Slotted test section walls--Flow
2. Perforated test section walls--Flow
3. Transonic test sections--Configurations
I. Chen, C. F.
II. Mears, J. W.

UNCLASSIFIED

UNCLASSIFIED

AEDC-TR-57-20
(Brown U. TR WT-23)
ASTIA DOCUMENT NO.:
AD-144320

Arnold Engineering Development Center, ARO, Inc., Tullahoma, Tennessee
EXPERIMENTAL AND THEORETICAL STUDY OF MEAN BOUNDARY CONDITIONS AT PERFORATED AND LONGITUDINALLY SLOTTED WIND TUNNEL WALLS by C. F. Chen and J. W. Mears, December 1957. 42 pp. (AEDC-TR-57-20) (Contract No. AF 40(600)-677) Unclassified Report

8 references

A mean boundary condition has been derived for the flow of an incompressible inviscid fluid along a longitudinally slotted wall taking into consideration the finite thickness of the slats. The flow was investigated near a wall along its longitudinal axis, and the results showed that the mean boundary condition was satisfied in the middle portion of this region.

1. Slotted test section walls--Flow
2. Perforated test section walls--Flow
3. Transonic test sections--Configurations
I. Chen, C. F.
II. Mears, J. W.

UNCLASSIFIED

UNCLASSIFIED

AEDC-TR-57-20
(Brown U. TR WT-23)
ASTIA DOCUMENT NO.:
AD-144320

The mean boundary condition for a perforated wall, derived by Maeder and Wood (Ref. 1), was investigated. The results showed that the mean boundary condition was not satisfied at either end of the test section. In the middle portion, the mean boundary condition would be satisfied if it were modified by an additive constant.

UNCLASSIFIED

UNCLASSIFIED

AEDC-TR-57-20
(Brown U. TR WT-23)
ASTIA DOCUMENT NO.:
AD-144320

The mean boundary condition for a perforated wall, derived by Maeder and Wood (Ref. 1), was investigated. The results showed that the mean boundary condition was not satisfied at either end of the test section. In the middle portion, the mean boundary condition would be satisfied if it were modified by an additive constant.

UNCLASSIFIED

UNCLASSIFIED

AEDC-TR-57-20
(Brown U. TR WT-23)
ASTIA DOCUMENT NO.:
AD-144320

The mean boundary condition for a perforated wall, derived by Maeder and Wood (Ref. 1), was investigated. The results showed that the mean boundary condition was not satisfied at either end of the test section. In the middle portion, the mean boundary condition would be satisfied if it were modified by an additive constant.

UNCLASSIFIED

UNCLASSIFIED

AEDC-TR-57-20
(Brown U. TR WT-23)
ASTIA DOCUMENT NO.:
AD-144320

The mean boundary condition for a perforated wall, derived by Maeder and Wood (Ref. 1), was investigated. The results showed that the mean boundary condition was not satisfied at either end of the test section. In the middle portion, the mean boundary condition would be satisfied if it were modified by an additive constant.

UNCLASSIFIED

Cut on dotted line

UNCLASSIFIED

AEDC-TR-57-20
(Brown U. TR WT-23)
ASTIA DOCUMENT NO.:
AD-144320

Arnold Engineering Development Center, ARO, Inc., Tullahoma, Tennessee
EXPERIMENTAL AND THEORETICAL STUDY OF MEAN BOUNDARY CONDITIONS AT PERFORATED AND LONGITUDINALLY SLOTTED WIND TUNNEL WALLS by C. F. Chen and J. W. Mears, December 1957. 42 pp. (AEDC-TR-57-20) (Contract No. AF 40(600)-677) Unclassified Report

8 references

A mean boundary condition has been derived for the flow of an incompressible inviscid fluid along a longitudinally slotted wall taking into consideration the finite thickness of the slats. The flow was investigated near a wall along its longitudinal axis, and the results showed that the mean boundary condition was satisfied in the middle portion of this region.

1. Slotted test section walls--Flow
2. Perforated test section walls--Flow
3. Transonic test sections--Configurations
I. Chen, C. F.
II. Mears, J. W.

UNCLASSIFIED

UNCLASSIFIED

AEDC-TR-57-20
(Brown U. TR WT-23)
ASTIA DOCUMENT NO.:
AD-144320

Arnold Engineering Development Center, ARO, Inc., Tullahoma, Tennessee
EXPERIMENTAL AND THEORETICAL STUDY OF MEAN BOUNDARY CONDITIONS AT PERFORATED AND LONGITUDINALLY SLOTTED WIND TUNNEL WALLS by C. F. Chen and J. W. Mears, December 1957. 42 pp. (AEDC-TR-57-20) (Contract No. AF 40(600)-677) Unclassified Report

8 references

A mean boundary condition has been derived for the flow of an incompressible inviscid fluid along a longitudinally slotted wall taking into consideration the finite thickness of the slats. The flow was investigated near a wall along its longitudinal axis, and the results showed that the mean boundary condition was satisfied in the middle portion of this region.

1. Slotted test section walls--Flow
2. Perforated test section walls--Flow
3. Transonic test sections--Configurations
I. Chen, C. F.
II. Mears, J. W.

UNCLASSIFIED

Cut on dotted line

UNCLASSIFIED

AEDC-TR-57-20
(Brown U. TR WT-23)
ASTIA DOCUMENT NO.:
AD-144320

Arnold Engineering Development Center, ARO, Inc., Tullahoma, Tennessee
EXPERIMENTAL AND THEORETICAL STUDY OF MEAN BOUNDARY CONDITIONS AT PERFORATED AND LONGITUDINALLY SLOTTED WIND TUNNEL WALLS by C. F. Chen and J. W. Mears, December 1957. 42 pp. (AEDC-TR-57-20) (Contract No. AF 40(600)-677) Unclassified Report

8 references

A mean boundary condition has been derived for the flow of an incompressible inviscid fluid along a longitudinally slotted wall taking into consideration the finite thickness of the slats. The flow was investigated near a wall along its longitudinal axis, and the results showed that the mean boundary condition was satisfied in the middle portion of this region.

1. Slotted test section walls--Flow
2. Perforated test section walls--Flow
3. Transonic test sections--Configurations
I. Chen, C. F.
II. Mears, J. W.

UNCLASSIFIED

UNCLASSIFIED

AEDC-TR-57-20
(Brown U. TR WT-23)
ASTIA DOCUMENT NO.:
AD-144320

Arnold Engineering Development Center, ARO, Inc., Tullahoma, Tennessee
EXPERIMENTAL AND THEORETICAL STUDY OF MEAN BOUNDARY CONDITIONS AT PERFORATED AND LONGITUDINALLY SLOTTED WIND TUNNEL WALLS by C. F. Chen and J. W. Mears, December 1957. 42 pp. (AEDC-TR-57-20) (Contract No. AF 40(600)-677) Unclassified Report

8 references

A mean boundary condition has been derived for the flow of an incompressible inviscid fluid along a longitudinally slotted wall taking into consideration the finite thickness of the slats. The flow was investigated near a wall along its longitudinal axis, and the results showed that the mean boundary condition was satisfied in the middle portion of this region.

1. Slotted test section walls--Flow
2. Perforated test section walls--Flow
3. Transonic test sections--Configurations
I. Chen, C. F.
II. Mears, J. W.

UNCLASSIFIED

UNCLASSIFIED

AEDC-TR-57-20
(Brown U. TR WT-23)
ASTIA DOCUMENT NO.:
AD-144320

The mean boundary condition for a perforated wall, derived by Maeder and Wood (Ref. 1), was investigated. The results showed that the mean boundary condition was not satisfied at either end of the test section. In the middle portion, the mean boundary condition would be satisfied if it were modified by an additive constant.

UNCLASSIFIED

UNCLASSIFIED

AEDC-TR-57-20
(Brown U. TR WT-23)
ASTIA DOCUMENT NO.:
AD-144320

The mean boundary condition for a perforated wall, derived by Maeder and Wood (Ref. 1), was investigated. The results showed that the mean boundary condition was not satisfied at either end of the test section. In the middle portion, the mean boundary condition would be satisfied if it were modified by an additive constant.

UNCLASSIFIED

UNCLASSIFIED

AEDC-TR-57-20
(Brown U. TR WT-23)
ASTIA DOCUMENT NO.:
AD-144320

The mean boundary condition for a perforated wall, derived by Maeder and Wood (Ref. 1), was investigated. The results showed that the mean boundary condition was not satisfied at either end of the test section. In the middle portion, the mean boundary condition would be satisfied if it were modified by an additive constant.

UNCLASSIFIED

UNCLASSIFIED

AEDC-TR-57-20
(Brown U. TR WT-23)
ASTIA DOCUMENT NO.:
AD-144320

The mean boundary condition for a perforated wall, derived by Maeder and Wood (Ref. 1), was investigated. The results showed that the mean boundary condition was not satisfied at either end of the test section. In the middle portion, the mean boundary condition would be satisfied if it were modified by an additive constant.

UNCLASSIFIED